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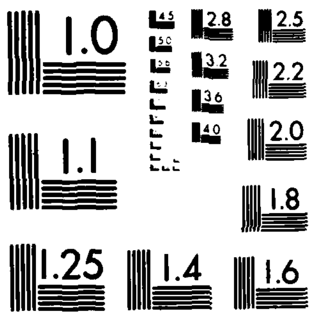

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ANALYSES TO DEVELOP MODELS
TO PROJECT FAILURE RATES AND
REPAIR COSTS OF ELECTRONIC
MODULES AND SUBASSEMBLIES

AGORA SYSTEMS, INC.

656 Quince Orchard Road, Suite 704
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Vol 3

21 September 1983

ANALYSES TO DEVELOP MODELS TO PROJECT FAILURE RATES AND REPAIR COSTS OF ELECTRONIC MODULES AND SUBASSEMBLIES

Prepared for

U.S. Army CECOM
Base Operations Procurement Branch
Fort Monmouth, NJ 07703

Under

Contract DAAB07-82-C-Q004

By

AGORA SYSTEMS, INC.
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SECTION 1.0

INTRODUCTION

1.1 STUDY OBJECTIVES

This report describes the work performed under Contract DAAB07-82-C-Q004 to develop failure rate and cost-to-repair models such that reliable estimates of the failure rate and repair/replacement costs of fielded systems can be generated based on information available during Advanced Development or at the beginning of Full Scale Development. This capability will assist logistics personnel develop more accurate failure rate prediction and budget cost requirements for Repair Depot in-service equipments when actual failure rate data and cost are not available.

In addition, information obtained by exercising these models can be fed back to the Project Office to support requirements trade-offs in the areas of reliability, testability and functional partitioning.

1.2 REQUIREMENTS AND CONSTRAINTS

Requirements imposed by CECOM cover two areas:

(1) a definition of the information generally available during the advanced development phase of the system which can be employed as inputs to the model, and

(2) scope and structure of the models.

In general, early system definition will consist of the following:

(1) A functional description of the system which will include such items as its name and intended function, the anticipated technology, built-in-test requirements and approximate size, volume, and cost.

(2) A crude description of the module complement which includes for each module type: its name, size, and function performed as well as the number of each module type per system.

(3) The intended fielded environment, e.g., ground mobile, airborne, fixed-wing, etc.; and

(4) The anticipated logistics support scenerio. This includes such data as the number and scheduling of systems fielded, number of field support levels, the availability of automatic test equipment, etc.

Most of this information will be available once functional requirements have been developed, and the remainder should be available from Advance Development proposals and preliminary design plans.

Additional constraints required by CECOM include the following:

(1) The overall model be structured as two distinct models; specifically, a failure rate model and a cost-to-repair model.

(2) The scope of the models be limited to electronic modules, circuit cards and subassemblies.

(3) The models are intended to be mechanized as computer programs. This implies that model accuracy will have priority when traded off against simplicity of implementation.

SECTION 2.0

FAILURE RATE MODEL

2.1 OVERALL APPROACH

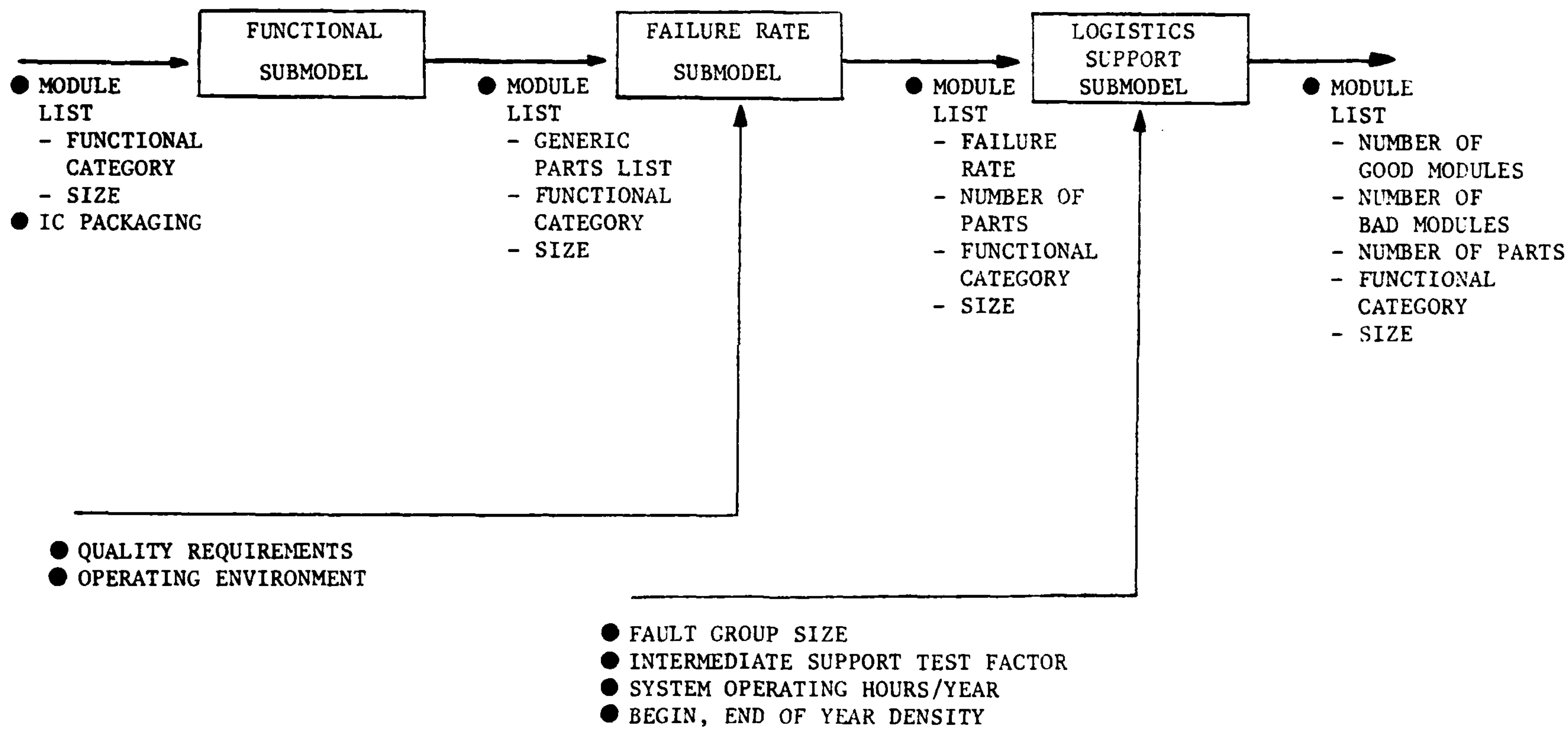
In formulating the basic technique of modeling module failure rates, it became obvious that it would be very advantageous to "capture" the massive amount of failure rate data embodied by the models of MIL-HDBK-217. This document models or characterizes the reliability of a large number of electronic components by considering, in addition to the intrinsic failure rate of the component, such factors as part quality, operating environment, and in-circuit stress levels.

This observation led to the partitioning of the overall failure rate model into three submodels as depicted in Figure 2-1.

(a) Functional Submodel - The functional submodel accepts as inputs preliminary system characteristics and module descriptions and outputs a representative or typical generic parts list. Note that these module descriptions are also required by Cost-to-Repair Model.

FIGURE 2-1

FAILURE RATE MODEL



(b) Failure Rate Submodel - The failure rate submodel accepts the generic parts list for each module, along with quality level and operating environment inputs and computes the intrinsic failure rate of each module in accordance with the reliability models in MIL-HDBK-217, and certain assumptions relating to the part's characteristics and in-circuit stress levels.

(c) Logistics Support Submodel - The logistics support submodel models the utilization of the system in the field, the occurrence of induced failures due to mishandling, etc., the effects of built-in-test equipment, and the detection of good modules at an intermediate maintenance facility. Thus, the outputs of this model are the number of both "good" and faulty modules entering the Repair Depot which is the primary input required to drive the Cost-to-Repair Model.

2.2 FUNCTIONAL SUBMODEL

The purpose of the functional submodel is to characterize electronic module by typical or representative parts lists. Thus, the inputs to this submodel must consist of certain information available early in the advanced definition phases of the system, and the outputs will be a generic parts list for each module type.

2.2.1 Data Base

The data base from which the functional submodel was developed consists of over 250 circuit and mechanical descriptions from nine different systems. These circuits are representative of a wide variety of functional capabilities and operating environments as indicated in Table 2-1.

One of the first outcomes of analyzing this data was the sensitivity of the results to the technology employed in these systems. Because of this, circuit descriptions from seven or eight additional systems could not be included in the data base because it proved all but impossible to project the design characteristics of these vintage systems to the technology levels of current day and future systems.

2.2.2 Generic Parts List

In order to establish a tractable and standardized basis of analyzing the data base, the concept of a generic parts list was developed. The effect of this was to reduce the domain of all possible electronic parts to a list of 49 representative

TABLE 2-1

FUNCTIONAL SUBMODEL DATA BASE

System	No. of Module Types
AN/TPQ-37(V) Radar Set	43
AN/PRC-77 Radio Set	36
AN/TPN-18A Radar Set	37
TR38F Communications Transponder	16
AN/TLQ-15 Countermeasures Set	17
AN/GSG-10(V) Artillary Fire Direction System	27
MK5 Missile Guidance System	66
Military Modular Multimission Spacecraft (M^3S)	11
Teletek Single Board Computer	1
Total	254

components as indicated in Table 2-2. This selection was performed with the objective of ending up with the smallest possible list commensurate with retaining all significant distinctions in the areas of component reliability, physical size, and cost.

2.2.3 Study Results

Once the generic parts list for each electronic module had been entered into the data base, a computer program was developed to analyze this data for correlation of parts list and module failure rates to the following input parameters:

(1) Module name or description

(2) System description or function

(3) Functional category

(4) Size

(5) Application environment

(6) Packaging technology

Little or no correlation was found with the module name or its description. Module names and descriptions (when available) tend to be vague and arbitrary. Similarly, the system description or function proved to be, in general, an unreliable indication of the characteristics of its electronic modules. For example, a target locating radar and a gun fire direction system could both contain essentially identical digital interface cards although the functions of these two systems are entirely different.

TABLE 2-2

GENERIC PARTS LIST

RANDOM LOGIC <100 GATES
RANDOM LOGIC 100-2000 GATES
RANDOM LOGIC 2000-7500 GATES
RANDOM LOGIC 7500-20,000 GATES
ROMS <2.2K BITS
BIPOLAR ROMS 2.2K-17K BITS
MOS ROMS 2.2K-17K BITS
BIPOLAR ROMS 17K-74K BITS
MOS ROMS 17K-74K BITS
BIPOLAR RAM <1.1K BITS
BIPOLAR RAM 1.1K-5K BITS
MOS RAM 1.1K-5K BITS
(MOS) RAM 5K-17K BITS
(MOS) RAM 17K-74K BITS
LINEAR IC 1-32 TRANSISTORS
LINEAR IC 33-100 TRANSISTORS
LINEAR IC 101-300 TRANSISTORS
TRANSISTOR NPN
TRANSISTOR PNP
FET
GEN PURPOSE DIODE
ZENER DIODE
LED
MICROWAVE DETECTOR
MICROWAVE MIXER
MICROWAVE POWER TRANSISTOR
OPTICAL ISOLATOR
RESISTOR, FIXED
RESISTOR, POWER
RESISTOR, TRIMMER
CAPACITOR, MILAR, MICA
CAPACITOR, CERAMIC
CAPACITOR, ELECTROLYTIC
VARIABLE CAPACITOR
PULSE TRANSFORMER
AUDIO TRANSFORMER
POWER TRANSFORMER
RF TRANSFORMER
RF COIL FIXED
RF COIL VARIABLE
RELAY
TOGGLE SWITCH
ROTARY SWITCH
COAX CONNECTOR
PWB CONNECTOR
2 SIDED BOARDS
MULTILAYER BOARDS
CRYSTAL
LAMP INCANDESCENT

Very good correlation, however, was obtained with the concept of functional categories which is the classification of electronic modules in accordance with a broad definition of the function they perform. This is based on the premise that all circuits of a given functional category will contain a somewhat identical mix of generic parts independently of the actual function the circuit is designed to perform. For example, all "digital" modules can be expected to consist of about the same number of SSI and MSI integrated circuits (all other factors being equal) despite the fact that an almost infinite variety of functions can be implemented with these circuits. After several iterations, eight functional categories were defined and are described in Table 2-3.

As expected, module size or board area is strongly correlated with the number of parts and module failure rate. This is true because space and volume are a premium in almost all military systems, and designers tend to fully populate their modules independently of board size.

Despite the fact that the number of parts is proportional to board area, it was found necessary to account for a difference in packaging density between different systems. Although the application environment was considered (e.g., avionics and manpack equipments tend to be more densely packaged than shelter mounted equipments), the circuit packaging technology employed (e.g., DIPS, Flatpacks, or LCC's) was found to be a more reliable indicator of module density.

TABLE 2-3

FUNCTIONAL CATEGORIES

	FUNCTIONAL CATEGORY	CHARACTERIZED BY:
1.	RF FRONT END	RF AND MICROWAVE COMPONENTS STRIP LINES, TUNABLE CIRCUITS CHIP CAPACITORS
2.	RF/IF	BACK END RF AND IF FUNCTIONS - AMPLIFICATION, DETECTION, FILTERING
3.	ANALOG	AUDIO, SERVO AND DC AMPLIFIERS, ANALOG FUNCTIONS, LINEAR REGULATORS
4.	DIGITAL	RANDOM LOGIC - DOMINATED BY DIGITAL SSI AND MSI INTEGRATED CIRCUITS
5.	POWER SUPPLY	SWITCHING REGULATORS
6.	DIGITAL INTERFACE	RANDOM LOGIC PLUS SPECIAL DISCRETE INTERFACE CONTROL CIRCUITRY, A/D AND D/A CONVERSION
7.	MEMORY	PREDOMINATELY RAM, ROM, OR PROM INTEGRATED CIRCUITS
8.	LSI	ONE OR MORE LSI RANDOM LOGIC DEVICES IN CONJUNCTION WITH SSI AND MSI SUPPORT CHIPS

The results of these studies are presented in Tables 2-4 and 2-5 which indicate the normalized generic parts list and the packaging factor, respectively, for each of the eight functional categories.

Note that since the parts list of Table 2-4 is normalized to 100 cm^2, the parts list for any module of a given functional category can be computed as:

$$PL = PL_N \quad \frac{(2.54)^2 \ in^2}{100 \ cm^2} \times A \times P_F$$

Where:

PL_N = Normalized Parts List (Table 2-4)

A = Circuit card area (in^2)

P_F = Packaging Density Factor (Table 2-5)

TABLE 2-4

NORMALIZED GENERIC PARTS LIST

GENERIC PARTS LIST	RF Front End	RF/IF	Analog	Power Supply	Digital	Digital Int.	Memory	LSI
RANDOM LOGIC < 100 GATES	-	-	1.7	.22	13.2	6.6	12.2	12.0
RANDOM LOGIC 100-2000 GATES	-	-	-	-	-	-	-	.38
RANDOM LOGIC 2000-7500 GATES	-	-	-	-	-	-	-	.48
RANDOM LOGIC 7500-20,000 GATES	-	-	-	-	-	-	-	.24
ROMS < 2.2K BITS	-	-	-	-	-	-	-	-
BIPOLAR ROMS 2.2K-17K BITS	-	-	-	-	-	-	10.8	2.77
MOS ROMS 2.2K-17K BITS	-	-	-	-	-	-	-	-
BIPOLAR ROMS 17K-74K BITS	-	-	-	-	-	-	-	-
MOS ROMS 17K-74K BITS	-	-	-	-	-	-	-	-
BIPOLAR RAM <1.1K BITS	-	-	-	-	-	-	-	-
BIPOLAR RAM 1.1K-5K BITS	-	-	-	-	-	-	2.3	-
MOS RAM 1.1K-5K BITS	-	-	-	-	-	-	-	.96
(MOS) RAM 5K-17K BITS	-	-	-	-	-	-	-	-
(MOS) RAM 17K-74K BITS	-	-	-	-	-	-	-	.77
LINEAR IC 1-32 TRANSISTORS	5.2	3.47	10.3	4.1	.04	6.1	4.2	.57
LINEAR IC 33-100 TRANSISTORS	-	-	-	-	-	-	-	-
LINEAR IC 101-300 TRANSISTORS	-	-	-	-	-	-	-	-
TRANSISTOR NPN	15.4	13.0	.85	4.3	.13	2.3	-	1.9
TRANSISTOR PNP	-	-	.27	-	.10	1.8	-	-
FET	-	-	.09	-	-		-	-
GEN PURPOSE DIODE	10.5	6.6	6.8	12.2	.52	12.0	-	.96
ZENER DIODE	-	.40	-	.25	.0030		-	-
LED	-	-	-	-	-	.44	-	-
MICROWAVE DETECTOR	-	-	-	-	-	-	-	-
MICROWAVE MIXER	.98	-	-	-	-	-	-	-
MICROWAVE POWER TRANSISTOR	-	-	-	-	-	-	-	-
OPTICAL ISOLATOR	-	-	-	-	-	-	-	-
RESISTOR, FIXED	84.8	72.0	62.5	41.0	3.1	45.9	43.7	25.9
RESISTOR, POWER	-	-	-	.18	-	-	-	.48
RESISTOR, TRIMMER	-	-	0.14	-	-	.33	-	-
CAPACITOR, MILAR, MICA	-	-	-	-	0.2	.75	-	-
CAPACITOR, CERAMIC	123	105	16.6	12.5	2.9	9.7	6.2	5.4
CAPACITOR, ELECTROLYTIC	-	-	3.0	5.1	.12	3.0	.28	2.2
VARIABLE CAPACITOR	13.4	-	-	-	-	-	-	-
PULSE TRANSFORMER	-	-	-	-	.01	2.2	-	-
AUDIO TRANSFORMER	-	-	-	-	-	.04	-	-
POWER TRANSFORMER	-	-	.38	2.9	-	-	-	-
RF TRANSFORMER	2.0	2.0	.46	.14	-	.33	-	-
RF COIL FIXED	28.4	33.5	.19	1.4	-	.15	-	-
RF COIL VARIABLE	-	-	-	-	-	-	-	-
RELAY	-	-	-	-	.01	.55	-	-
TOGGLE SWITCH	-	-	-	-	-	.11	-	-
ROTARY SWITCH	-	-	-	-	-	-	-	-
COAX CONNECTOR	.02	-	-	-	-	.09	-	-
PWB CONNECTOR	-	-	.92	.75	1.0	.84	1.0	1.0
2 SIDED BOARDS	1.0	1.0	.28	.25	.59	.51	.33	1.0
MULTILAYER BOARDS	-	-	.71	.75	.41	.49	.66	-
CRYSTAL	.98	.40	-	-	.04	.03	-	.72
LAMP INCANDESCENT	-	-	-	-	-	-	-	-

TABLE 2-5

PARTS LIST PACKAGING FACTORS

FUNCTIONAL CATEGORY	PACKAGING TECHNOLOGY		
	DIP	FLATPACK	LCC
RF FRONT END	0.5	1.0	1.0
RF/IF	0.5	1.0	1.0
ANALOG	1.0	2.0	3.0
POWER SUPPLY	1.0	2.0	3.0
DIGITAL	1.0	4.0	8.0
DIGITAL INTERFACE	1.0	2.0	3.0
MEMORY	1.0	2.0	3.0
LSI	1.0	1.5	2.0

2.3 FAILURE RATE SUBMODEL

MIL-HDBK-217 (Revision D) failure rate models were formulated for each of the 49 generic part types discussed previously. These models cover twenty environmental categories as well as two quality levels, "Mil-Spec" and "Commercial". In addition to these parameters, MIL-HDBK-217 models require the specification of part characteristics (e.g., number of gates), materials, in-circuit stress levels, and operating temperatures. Appropriate values have been estimated for each of these parameters as indicated in the model descriptions that follow.

Case or junction temperatures necessary for each model have been developed by assuming a typical ambient temperature for each of the environmental categories (refer to Table 2-6) and then estimating the temperature rise above ambient as appropriate for each generic part.

ENVIRONMENT	DESIGNATION	AMBIENT TEMPERATURE (T_A)	π_E - MONOLITHIC INTEG. CIRCUITS	π_E - TRANSISTORS & DIODES	π_E - MICROWAVE DETECTORS, MIXER	π_E - OPTO-ELECTRONIC DEVICES	π_E - MICROWAVE TRANSISTORS	π_E - FIXED RESISTORS	π_E - POWER RESISTORS	MMER RESISTORS	ACITORS	TORS	TORS
GROUND, BENIGN	GB	30°C	0.38	1.0	1.0	1.0	1.0	1.0	1.0				
GROUND, FIXED	GF	40°C	2.5	5.8	6.4	2.4	2.0	2.9	1.5				
GROUND, MOBILE	GM	55°C	4.2	18	31	7.8	7.8	8.3	8.3				
SPACE, FLIGHT	SF	30°C	0.90	1.0	1.0	1.0	1.0	1.0	0.6				
MANPACK	MP	35°C	3.8	12	35	7.7	7.4	8.5	11				
NAVAL, SHELTERED	NS	40°C	4.0	9.8	11	5.7	4.7	5.2	4.9				
NAVAL, UNSHELTERED	NU	75°C	5.7	21	33	11	11	12	14				
NAVAL, UNDERSEA UNSHELTERED	NUU	20°C	6.3	20	58	13	12	14	17				
NAVAL, SUBMARINE	NSB	40°C	4.0	9.8	8.0	3.7	3.6	4.0	4.9				
NAVAL, HYDROFOIL	NH	40°C	5.9	19	54	12	11	13	16				
AIRBORNE, INHABITED TRANSPORT	AIT	55°C	3.5	12	25	2.8	3.0	2.8	4.0				
AIRBORNE, INHABITED FIGHTER	AIF	55°C	7.0	25	50	5.6	6.0	5.7	8.0				
AIRBORNE, UNINHABITED TRANSPORT	AUT	71°C	4.0	20	40	4.2	4.0	5.7	8.5				
AIRBORNE, UNINHABITED FIGHTER	AUF	71°C	6.0	40	80	8.4	8.0	11	17				
AIRBORNE, ROTARY WINGED	ARW	55°C	8.5	27	78	17	16	19	23				
MISSILE, LAUNCH	ML	55°C	13.0	41	120	26	25	29	36				
CANNON, LAUNCH	CL	40°C	220	690	2000	450	250	490	610				
UNDERSEA, LAUNCH	USL	35°C	11.0	36	110	23	22	25	31				
MISSILE, TREE FLIGHT	MFF	45°C	3.9	12	36	7.8	7.5	8.6	11				
AIR BREATHING MISSILE, FLIGHT	MFA	45°C	5.4	17	50	11	11	13	15				

TABLE 2-6

ENVIRONMENTAL MODE FACTOR

2.3.1 Monolithic Integrated Circuits

Device failure rate (λ) in F/10^6 hours is modeled as:

$$\lambda = \pi_Q [C_1 \pi_T \pi_V \pi_{PT} + C_2 + C_3) \pi_E] \pi_L$$

Where:

π_Q = Quality Factor

π_Q = 1 for the "Mil-Spec" quality and which implies that the part was purchased in full accordance with MIL-M-38510, Class B requirements

π_Q = 17.5 for the "Commercial" quality level which implies that the part is hermetically sealed or encapsulated with inorganic material but was purchased with no screening beyond the manufacturer's regular quality assurance practices

π_T = Temperature Acceleration Factor

$\pi_T = 0.1e^{-X}$

Where:

$$X = \frac{1}{T_j + 273^o} - \frac{1}{298^o}$$

and,

$T_j = T_A + \Delta T$

The ambient temperature (T_A) for each environmental category is presented in Table 2-6. The assumed temperature rise from ambient to junction (ΔT) and the temperature coefficient (A) are set forth in Table 2-7 for each applicable generic part type. Thus, π_T will be a function of the environmental category as well as the generic part type.

TABLE 2-7

MONOLITHIC INTEGRATED CIRCUIT MODEL PARAMETERS

GENERIC PART	No. of Circuit Elements	No. of Prns	ΔT (C°)	A (Factor of π_T)	C1	C2	C3
RANDOM LOGIC <100 GATES (BIPOLAR)	48G	16	10	5214	.0094	.0009	.0056
RANDOM LOGIC 100-2000 GATES (BIPOLAR)	875G	28	25	5214	.0455	.0012	.0100
RANDOM LOGIC 2000-7500 GATES (MOS)	4500G	40	35	6952	.051	.0017	.0150
RANDOM LOGIC 7500-20K GATES (MOS)	9375G	64	45	6952	.068	.0020	.0250
BIPOLAR ROM <2.2K BITS	1KB	18	15	5214	.013	.0006	.0064
BIPOLAR ROM 2.2K-17K BITS	8KB	24	30	5214	.029	.0014	.0090
MOS ROM 2.2K-17K BITS	16KB	24	20	6952	.055	.0024	.0090
MOS ROM 17K-38K BITS	32KB	28	25	6952	.100	.0042	.0100
MOS ROM 38K-74K BITS	64KB	28	30	6952	.134	.0055	.0100
BIPOLAR RAM <1.1K BITS	1KB	16	25	5214	.080	.0013	.0056
BIPOLAR RAM 1.1K-5K BITS	4KB	18	35	5214	.265	.0040	.0064
MOS RAM 1.1K-5K BITS	4KB	18	22	6952	.080	.0039	.0064
MOS RAM 5K-17K BITS	16KB	22	30	6952	.186	.0088	.0080
MOS RAM 17K-74K BITS	64KB	24	35	6952	.434	.0200	.0090
LINEAR IC 1-32 TRANSISTORS	24T	8	10	7532	.019	.0044	.0026
LINEAR IC 33-100 TRANSISTORS	84T	14	15	7532	.050	.0086	.0048
LINEAR IC 101-300 TRANSISTORS	250T	16	25	7532	.117	.0154	.0056

π_V - Voltage Derating Stress Factor

π_V = 1.0 which implies no high voltage (>5VDC) CMOS circuits

π_{PT} - Programming Technique Factor

π_{PT} is applicable only for ROM and programmable ROM devices and is assumed to equal 1.0

π_E - Application Environments Factor

Refer to Table 2-6

C_1 and C_2 - Device Complexity Failure Rate

C_1 and C_2 are a function of the circuit technology (TTL, LSTTL, NMOS, CMOS, etc.) and the circuit complexity (number of gates, bits, or transistors). Values for C_1 and C_2 are presented in Table 2-7 for each applicable generic part type.

C_3 - Package Complexity Failure Rate

C_3 is a function of the packaging technology (DIP's, Flatpack, Cans, etc.) and the number of package pins. Note that a hermetic, solder sealed DIP is assumed for all devices. Values for C_3 are provided by Table 2-7 for all applicable generic part types.

π_L - Device Learning Factor

π_L = 1.0 which assumes the device is a mature product

2.3.2 Discrete Semiconductors

The failure rate (λ) for discrete semiconductors is modeled as:

$$\lambda = \lambda_b(\pi_E \; \pi_A \; \pi_Q \; \pi_R \; \pi_{S2} \; \pi_C)$$

Where:

λ_b = Base Failure Rate

$\lambda_b = Ae^X$

And,

$$X = \frac{N_T}{273 + T + (\Delta T)S} + \left[\frac{273 + T + (\Delta T)S}{T_M}\right]^P$$

Where A, N_T, T_M, P and ΔT are scaling and shaping parameters and are presented in Table 2-8 for each of the applicable generic part types.

T is the device case temperature and is assumed to be 20° above the ambient temperature (which is a function of the environmental category.

S is the ratio of operating power to maximum rated power and is assumed to be equal to 0.5.

π_E - Environmental Category Factor

Refer to Table 2-6

π_A - Application Factor

π_A = 1.5 implies device application is that of providing linear gain

π_Q = Quality Factor

π_Q = 0.20 for the "Mil Spec" quality level; implies that the part is procured to full JANTX requirements

TABLE 2-8

DISCRETE SEMICONDUCTOR MODEL PARAMETERS

Generic Part	A	N_T	T_M	P	ΔT
Transistor NPN	.0227	-1052	448	10.5	150
Transistor PNP	.0718	-1324	448	14.2	150
FET	.624	-1162	448	13.8	150
General Purpose Diode	.258	-2138	448	17.7	150
Zener Diode	.0264	-800	448	14.0	150
Microwave Detector	.490	-392	423	16.6	125
Microwave Mixer	.665	-394	423	15.6	125

π_a = 5.0 for the "Commercial" quality level; implies that the part is hermetically sealed but procured to less than JAN requirements

π_R - Power Stress Factor

π_R = 1.0 implies power dissipation $\leq$ 1 watt

π_{S2} - Voltage Stress Factor

π_{S2} = 1.0 implies that the applied VCE is 65% of the rated VCEO

π_C - Complexity Factor

π_C = 1.0 implies a single device in the package

2.3.3 Opto-Electronic Semiconductor Devices

The failure rate (λ) for opto-electronic semiconductor devices is modeled as:

$$\lambda = \lambda_b \ \pi_T \ \pi_E \ \pi_Q$$

Where:

λ - Base Failure Rate

$\lambda_b = 6.5 \times 10^5$ F/10^6 hours for an LED

Or,

λ_b = .0001 F/10^6 hours a single isolator with a photo diode detector

π_T - Temperature Factor

$$\pi_T = 8.01 \times 10^{12} \exp \frac{-8111}{T_j + 374}$$

Where:

T_j is assumed to be 20°C above the ambient temperature

π_E - Environmental Factor

Refer to Table 2-6

π_Q - Quality Factor; defined identically to the quality factor for discrete semiconductors

2.3.4 Microwave Transistors

The failure rate (λ) for microwave transistors is modeled as:

$$\lambda = \lambda_b \ \pi_Q \ \pi_T \ \pi_A \ \pi_F \ \pi_M \ \pi_E$$

Where:

λ_b - Base Failure Rate

λ_b = 0.40 F/10^6 hours

π_Q - Quality Factor

π_Q = 2 for "Mil-Spec" quality level; implies that the device is procured to JANTX specifications

π_Q = 10 for "Commercial" quality level; implies that the device is hermetically sealed and procured to less than JAN specifications

π_T - Temperature Factor

For devices with refractory metal-gold metallization and operated under conditions of Vc/BV_{CES} = 0.5, then:

π_T = 0.012 (T-75)

Where:

T is the peak junction temperature and is assumed to be 100°C above the ambient temperature

π_A - Application Factor

π_A - 2 implies that the device is operated as a pulse amplifier with a duty factor of $\geq$ 5% and $\leq$ 30%

π_F - Operating Power and Frequency Factor

π_F = 1.5 implies that the device is operated at a frequency of 1.0 - 1.5 GHz and at a power level of $\leq$ 30 watts

π_M - Matching Factor

π_M = 1 implies that both the input and output are matched

π_E - Environmental Category Factor

Refer to Table 2-6

2.3.5 Resistors

The failure rate (λ) of fixed resistors is:

$$\lambda = \lambda_b \ \pi_E \ \pi_R \ \pi_Q$$

Where:

λ_b - Base failure rate

$\lambda_b = Ae^x$

And,

$$X = B \left[\frac{T + 273}{N_T}\right]^G + \left[\left(\frac{S}{N_S}\right)\left(\frac{T + 273}{273}\right)^J\right]^H$$

A, B, N_T, N_S, G, J, and H are scaling and shaping parameters and are specified in Table 2-9

T = Ambient temperature as a function of the application environment in accordance with Table 2-6

S = Ratio of operating power to rated power and is assumed to be 0.5

TABLE 2-9

RESISTOR FAILURE RATE MODEL PARAMETERS

Generic Part	Style	A	B	N_T	G	N_S	H	J
RESISTOR, FIXED	RC	4.5×10^{-9}	12	343	1	0.6	1	1
RESISTOR, POWER	RW	1.48×10^{-3}	1	298	2	0.5	1	1
RESISTOR, TRIMMER	RTR	3.7×10^{-3}	1	358	5	1	1	1

π_E - Environmental Mode Factor

Refer to Table 2-6

π_R - Resistance Factor

π_R = 1.1 implies resistance values in the range of 100K - 1M ohms

π_Q - Quality Factor

π_Q = 1 for the "Mil-Spec" quality level; implies that the part is procured to the appropriate MIL-R specification with Quality Level M specified

π_Q = 15 for the "Commercial" quality level

The failure rate (λ) for variable resistors is modeled as:

$$\lambda = \lambda_b \; \pi_T \; \pi_R \; \pi_V \; \pi_E \; \pi_Q$$

Where:

λ_b = Base failure rate as defined previously for fixed resistors and specified in Table 2.9

π_T = Potentrometer *Taps Factor*

π_T = 1.0 implies three connections to potentrometer

π_R - Resistance Factor

π_r = 1.4 implies resistance values in the range of 2K to 5K ohms

π_V = Voltage Factor

π_V = 1.0 implies the ratio of applied voltage to rated voltage as 0.5

π_E = Environmental Mode Factor

Refer to Table 2-6

π_Q = Quality Factor as defined previously for fixed resistors

2.3.6 Capacitors

The failure rate (λ) of capacitors is modeled as:

$$\lambda = \lambda_b \; \pi_E \; \pi_{CV} \; \pi_{SR} \; \pi_Q$$

Where:

λ_b - Base Failure Rate

$$\lambda_b = A \left[\left(\frac{S}{N_S} \right)^H + 1 \right] e^X$$

And,

$$X = B \left[\frac{T + 273}{N_T} \right]^G$$

S = Ratio of operating voltage to rated voltage and is assumed to be 0.5

T = Ambient temperature as a function of the application environment in accordance with Table 2-6

A, B, N_S, N_T, H, G are sealing and shaping parameters and are specified in Table 2-10

π_E - Environmental Mode Factor

Refer to Table 2-6

π_{CV} - Capacitance Value Factor

π_{CV} = 1.0 for the nominal value of capacitance for each component class as indicated in Table 2-10

π_{SR} - Series Resistance Factor

π_{SR} = 0.4 for Style CSR; this assumes a circuit resistance of 0.6 ohms/volt

π_{SR} = 1.0 for all other styles

TABLE 2-10

CAPACITOR FAILURE RATE MODEL PARAMETERS

Generic Part	Style	Rating	A	B	N_T	G	N_S	H	Nominal Capacitance	π_Q- Commercial Quality Level
MILAR	CPV	125°C	5.0×10^{-4}	2.5	398	18.0	0.4	5	.027uF	30
CERAMIC	CK	125°C	3.0×10^{-4}	1.0	398	1.0	0.3	3	3300pF	10
ELECTROLYTIC	CSR	125°C	3.75×10^{-3}	2.6	398	9.0	0.4	3	1uF	10
VARIABLE	CV	85°C	9.0×10^{-3}	1.59	358	10.1	0.17	3	N/A	5

π_Q - Quality Factor

π_Q = 1 for the "Mil-Spec" quality level; implies that the part is procured to the appropriate MIL-C specification with Quality Level M specified

π_Q is defined by Table 2-10 for the "Commercial" quality level

2.3.7 Inductive Devices

The failure rate (λ) for transformers and coils is modeled as:

$$\lambda = \lambda_b \; \pi_E \; \pi_Q \; \pi_C$$

Where:

λ_b - Base Failure Rate

$_b = Ae^X$

And,

$$X = \left[\frac{T_{HS} + 273}{N_T}\right]^G$$

T_{HS} = Hot spot temperature and equals the estimated temperature rise (Δ T) above the ambient temperature (T_A); Δ T is specified in Table 2-11 for each applicable component

A, N_T, G are scaling and shaping parameters and are specified in Table 2-11 for the indicated rated maximum operating temperature

π_E - Environmental Mode Factor

Refer to Table 2-6

π_Q - Quality Factor

π_Q = 1 is for the "Mil-Spec" quality level implies that the part is procured to the appropriate MIL-C specification

π_Q is defined by Table 2-11 for the "Commercial" quality level

TABLE 2-11

TRANSFORMER AND INDUCTOR FAILURE RATE MODEL

Generic Part	Max. Rated Operating Temperature	ΔT	A	N_T	G	π_Q-Commerical Quality Level
Pulse Transformer	130°	10°	.0228	364	8.7	3.5
Audio Transformer	130°	10°	.0456	364	8.7	2.5
Power Transformer	130°	30°	.0122	364	8.7	4.0
RF Transformer	130°	10°	.0182	364	8.7	2.5
RF Coil Fixed	125°	10°	7.28×10^{-3}	364	8.7	5.0
RF Coil Variable	125°	10°	7.28×10^{-3}	364	8.7	5.0

π_C - Construction Factor

π_C = 1 for fixed devices

π_C = 2 for variable devices

2.3.8 Relays

The failure rate (λ) for relays is modeled as:

$$\lambda = \lambda_b \ \pi_E \ \pi_{cyc} \ \pi_C \ \pi_F \ \pi_Q$$

Where:

λ_b - Base Failure Rate

$\lambda_b = Ae^X$

And,

$$X = \left(\frac{T_A + 273}{N_T}\right)^G + \left(\frac{S}{N_S}\right)^H$$

T_A is the ambient temperature and is a function of the environmental category

S is the ratio of the operating load current to the rated resistive load current and is assumed to be 0.5

A, N_T, N_S, G, H are model parameters and, for relays with a maximum rated ambient temperature of 125°C and with resistive loads, are specified as follows:

$A = 5.4 \times 10^{-3}$
$N_T = 377.0$
$N_S = 0.2$
$G = 10.4$
$H = 2.0$

π_E - Environmental Mode Factor

Refer to Table 2-6

π_{cyc} - Cycling Rate Factor

π_{cyc} = 1.0 implies 1 cycle/hour

π_C - Contact Form Factor

π_C = 3.0 implies contact form is DPDT

π_F - Application and Construction Factor

π_F = 5.0 implies general purpose applications with a balanced armature

π_Q - Quality Factor

π_Q = 1 for the "Mil-Spec" quality level

π_Q = 6 for the "Commercial" quality level

2.3.9 Switches

The failure rate (λ) for switches is modeled as:

$$\lambda = \lambda_b \ \pi_E \ \pi_{cyc} \ \pi_C \ \pi_L \ \pi_Q$$

Where:

λ_b - Base Failure Rate

λ_b = .00045 for toggle switches

λ_b = .0067 + .00003n for rotary switches

Where:

n is the number of contacts and is assumed to be 24

π_E - Environmental Mode Factor

Refer to Table 2-6

π_{cyc} - Cycling Rate Factor

π_{cyc} = 1.0 cycle/hour for toggle switches

π_{cyc} = 30 cycles/hour for rotary switches

π_C - Contact Form Factor

π_C = 1.5 for toggle switches: implies contact form DPST

π_C = 1.0 for rotary switches

π_L - Load Factor

π_L = 1.48 for resistive loads when the ratio of the operating load current to the rated load current is 0.5

π_Q - Quality Factor

π_Q = 1 for the "Military" quality level

π_Q = 20 for the "Commercial" quality level for toggle switches

π_Q = 50 for the "Commercial quality level for rotary switches

2.3.10 Connectors

The failure rate (λ) for connectors is modeled as:

$$\lambda = \lambda_b \ \pi_E \ \pi_P \ \pi_K \ \pi_Q$$

Where:

λ_b - Base Failure Rate

$\lambda_b = Ae^X$

$$X = \left[\frac{N_T}{T + 273}\right] + \left[\frac{T + 273}{T_o}\right]^P$$

T = operating temperature and equals the estimated rise in temperature (ΔT) above the ambient temperature (T_A) as specified in Table 2-12

A, N_T, T_o, and P are model parameters and are specified in Table 2-12

π_E - Environmental Factor

Refer to Table 2-6

π_P - Active Pin Factor

Refer to Table 2-12

π_K - Mating/Unmating Factor

π_K is a function of the application environment and is specified in Table 2-6.

π_Q - Quality Factor

π_Q = 1 for the "Mil-Spec" quality factor

π_Q = 3 for the "Commercial" quality factor

TABLE 2-12

CONNECTOR FAILURE RATE MODEL PARAMETERS

Generic Part	A	To	N_T	P	ΔT	No. of Pins	π_P
Coax Connector	0.19	373	-1298	4.25	5°C	2	1.36
PWB Connector	0.216	423	-2074	4.66	10°C	40	7.42

2.3.11 Printed Wiring Boards

The failure rate (λ) of the combination of printed wiring boards (PWB) and solder connections is modeled as:

$$\lambda = (\lambda_{b1} N_H + \lambda_{b2} N_C) \; \pi_E F_S$$

Where:

λ_{b1} - Base Failure Rate for PWB's

$\lambda_{b1} = 6 \times 10^{-6}$ F/10^{-6} hours for double sided boards

$\lambda_{b1} = 5 \times 10^{-4}$ F/10^{6} hours for multi-layer boards

N_H - Number of plated through holes/in^2

N_H = 10/in^2 assumed for double sided boards

N_H = 15/in^2 assumed for multi-layer boards

λ_{b2} - Base Failure Rate for connections

$\lambda_{b2} = 8 \times 10^{-5}$ implies connection technique is reflow soldering

N_C - Number of connections/in^2

N_C = 20/in^2 assumed by model

π_E - Environmental Mode Factor

Refer to Table 2-6

F_S - Scaling Factor used for computational convenience since the reference area of the Generic Parts List is 100 square centimeters rather than square inches

$F_S = 100/(2.54)^2 = 15.5$

2.3.12 Miscellaneous Components

The failure rates (λ) of crystals and incandescent lamps are modeled as follows:

$$\lambda \text{ (quartz crystal)} = 0.2F/10^6 \text{ hours}$$

$$\lambda \text{ (incandescent lamp)} = 1.0F/10^6 \text{ hours}$$

Note that sufficient data to develop sensitivities to application environments and quality levels is not available

2.3.13 Failure Rate Submodel Summary

The failure rate for each of twenty application environments as well as two applicable quality factors for each generic part is presented in Table 2-13.

The intrinsic failure rate for each module type can be computed as:

$$FI_M = \sum^{i}(PL_{Mi} \times FR_{Ei} \times \pi_{Qi})$$

Where:

FI_M = Intrinsic Failure Rate for module M

PL_{Mi} = Part List for module M

FR_{Ei} = Generic Failure Rate for part i under application environment E

π_{Qi} = Quality Factor for part i and quality level Q

GENERIC PART	π_Q "MIL SPEC"	π_Q "COMMERCIAL"	GENERIC FAILURE RATE ($F/10^6$ HOURS) AIF	AIT	ARW	AUF	AUT	CL
RANDOM LOGIC < 100 GATES	1.0	17.5	.056	.031	.066	.063	.035	1.5
RANDOM LOGIC 100-2000 GATES	1.0	17.5	.15	.094	.16	.24	.19	3.1
RANDOM LOGIC 2000-7500 GATES	1.0	17.5	.48	.40	.51	.93	.84	4.7
RANDOM LOGIC 7500-20,000 GATES	1.0	17.5	1.4	1.2	1.4	2.6	2.5	8.3
ROMS < 2.2K BITS	1.0	17.5	.066	.04	.08	.09	.06	1.7
BIPOLAR ROMS 2.2K-17K BITS	1.0	17.5	.14	.10	.15	.19	.15	2.5
MOS ROMS 2.2K-17K BITS	1.0	17.5	.31	.26	.33	.62	.56	3.0
BIPOLAR ROMS 17K-74K BITS	1.0	17.5	.49	.44	.52	1.0	.96	3.7
MOS ROMS 17K-74K BITS	1.0	17.5	.79	.73	.82	1.6	1.5	4.1
BIPOLAR RAM < 1.1K BITS	1.0	17.5	.24	.21	.25	.41	.38	1.9
BIPOLAR RAM 1.1K-5K BITS	1.0	17.5	.69	.65	.70	1.2	1.2	2.7
MOS RAM 1.1K-5K BITS	1.0	17.5	.33	.29	.35	.70	.65	2.5
(MOS) RAM 5K-17K BITS	1.0	17.5	2.0	1.9	2.1	4.4	4.3	5.7
(MOS) RAM 17K-74K BITS	1.0	17.5	3.1	3.0	3.1	6.7	6.5	7.9
LINEAR IC 1-32 TRANSISTORS	1.0	17.5	.088	.063	.10	.16	.13	1.6
LINEAR IC 33-100 TRANSISTORS	1.0	17.5	.23	.18	.25	.48	.42	3.0
LINEAR IC 101-300 TRANSISTORS	1.0	17.5	.75	.68	.78	1.7	1.6	4.9
TRANSISTOR NPN	0.2	5.0	.086	.041	.092	.18	.091	1.9
TRANSISTOR PNP	0.2	5.0	.14	.067	.15	.29	.14	2.9
FET	0.2	5.0	1.6	.78	1.8	3.5	1.7	36
GEN PURPOSE DIODE	0.2	5.0	.026	.013	.028	.06	.029	.55
ZENER DIODE	0.2	5.0	.09	.043	.097	.18	.091	2.1
LED	0.2	5.0	.22	.11	.66	.88	.44	6.1
MICROWAVE DETECTOR	0.6	1.4	12	5.8	18	19	9.8	-
MICROWAVE MIXER	0.6	1.4	16	8.1	25	34	17	-
MICROWAVE POWER TRANSISTOR	0.5	2.5	6.8	3.4	18	11	3.4	230
OPTICAL ISOLATOR	0.2	5.0	2.5	1.2	7.6	12	5.0	89
RESISTOR, FIXED	1.0	15	.038	.019	.13	.14	.07	1.8
RESISTOR, POWER	1.0	15	1.1	.54	2.5	4.4	2.2	47
RESISTOR, TRIMMER	1.0	15	.16	.078	.61	.37	.19	13
CAPACITOR, MILAR, MICA	1.0	30	.018	.0088	.044	.050	.026	1.1
CAPACITOR, CERAMIC	1.0	10	.20	.099	.28	.41	.20	6.8
CAPACITOR, ELECTROLYTIC	1.0	10	.082	.041	.14	.21	.11	3.2
VARIABLE CAPACITOR	1.0	5.0	4.8	2.5	16	50	25	340
PULSE TRANSFORMER	1.0	3.5	.082	.043	.094	.14	.069	2.0
AUDIO TRANSFORMER	1.0	2.5	.16	.086	.20	.28	.14	4.0
POWER TRANSFORMER	1.0	4.0	.69	.36	.79	1.3	.63	15
RF TRANSFORMER	1.0	2.5	.66	.34	.75	1.1	.57	16
RF COIL FIXED	1.0	5.0	.059	.031	.067	.079	.039	1.2
RF COIL VARIABLE	1.0	5.0	.12	.062	.13	.16	.078	2.4
RELAY	1.0	6.0	1.4	.68	7.9	5.9	3.0	-
TOGGLE SWITCH	1.0	20	.010	.0050	.046	.10	.050	1.2
ROTARY SWITCH	1.0	50	3.3	1.6	15	33	16	400
COAX CONNECTOR	1.0	3.0	.30	.15	.57	.40	.20	5.3
PWB CONNECTOR	1.0	3.0	.15	.074	.28	.21	.11	2.6
2 SIDED BOARDS	1.0	1.0	.21	.10	.49	.47	.23	13
MULTILAYER BOARDS	1.0	1.0	.86	.44	2.3	1.2	1.7	60
CRYSTAL	1.0	1.0	.20	.20	.20	.20	.20	.2[illegible]
LAMP INCANDESCENT	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

TABLE 2-13

GENERIC FAILURE RATE SUMMARY

GENERIC PART	GENERIC FAILURE RATE ($F/10^6$ HOURS)							
	G_B	G_F	G_M	M_L	M_{FA}	M_{FF}	M_P	N_H
RANDOM LOGIC < 100 GATES	.005	.021	.036	.098	.042	.032	.029	.045
RANDOM LOGIC 100-2000 GATES	.028	.071	.10	.23	.12	.10	.082	.12
RANDOM LOGIC 2000-7500 GATES	.089	.20	.42	.60	.30	.27	.19	.27
RANDOM LOGIC 7500-20,000 GATES	.31	.61	1.3	1.6	.86	.81	.53	.73
ROMS < 2.2K BITS	.007	.03	.04	.11	.05	.04	.03	.05
BIPOLAR ROMS 2.2K-17K BITS	.02	.06	.10	.20	.10	.08	.07	.10
MOS ROMS 2.2K-17K BITS	.05	.12	.27	.39	.19	.17	.11	.16
BIPOLAR ROMS 17K-74K BITS	.09	.20	.45	.59	.30	.28	.18	.26
MOS ROMS 17K-74K BITS	.16	.33	.74	.90	.48	.46	.28	.39
BIPOLAR RAM < 1.1K BITS	.06	.11	.22	.29	.16	.15	.11	.14
BIPOLAR RAM 1.1K-5K BITS	.21	.35	.66	.75	.47	.45	.30	.38
MOS RAM 1.1K-5K BITS	.06	.13	.30	.40	.20	.19	.12	.17
(MOS) RAM 5K-17K BITS	.46	.88	2.0	2.2	1.2	1.2	.69	.95
(MOS) RAM 17K-74K BITS	.71	1.3	3.0	3.2	1.8	1.8	1.1	1.4
LINEAR IC 1-32 TRANSISTORS	.009	.031	.068	.13	.058	.047	.037	.056
LINEAR IC 33-100 TRANSISTORS	.030	.084	.19	.31	.14	.12	.086	.13
LINEAR IC 101-300 TRANSISTORS	.13	.29	.69	.88	.44	.40	.24	.36
TRANSISTOR NPN	.0025	.016	.062	.14	.05	.036	.031	.051
TRANSISTOR PNP	.0036	.024	.10	.23	.078	.055	.046	.079
FET	.047	.21	1.2	2.7	.96	.68	.59	.99
GEN PURPOSE DIODE	.00068	.0031	.019	.043	.015	.011	.0089	.015
ZENER DIODE	.0027	.012	.065	.15	.053	.038	.034	.056
LED	.0065	.033	.30	1.0	.21	.15	.075	.16
MICROWAVE DETECTOR	.18	1.3	7.1	28	10	7.4	6.6	11
MICROWAVE MIXER	.25	1.7	10	39	14	10	9.1	15
MICROWAVE POWER TRANSISTOR	.79	1.9	8.9	29	11	7.6	6.4	10
OPTICAL ISOLATOR	.074	.37	3.5	70	2.4	1.4	.85	1.9
RESISTOR, FIXED	.026	.0011	.055	.19	.06	.039	.026	.048
RESISTOR, POWER	.072	.18	.89	3.7	1.4	1.0	.89	1.4
RESISTOR, TRIMMER	.014	.036	.18	.94	.34	.24	.21	.35
CAPACITOR, MILAR, MICA	.0021	.005	.017	.068	.12	.020	.019	.029
CAPACITOR, CERAMIC	.011	.018	.091	.42	.17	.13	.12	.18
CAPACITOR, ELECTROLYTIC	.0056	.014	.053	.21	.083	.060	.052	.084
VARIABLE CAPACITOR	.32	1.2	4.3	25	8.8	6.5	5.7	8.9
PULSE TRANSFORMER	.0029	.019	.047	.14	.052	.038	.035	.053
AUDIO TRANSFORMER	.0058	.038	.094	.28	.10	.076	.070	.11
POWER TRANSFORMER	.021	.14	.39	1.2	.41	.30	.25	.40
RF TRANSFORMER	.024	.15	.37	1.1	.41	.30	.28	.42
RF COIL FIXED	.0016	.011	.034	.10	.03	.022	.018	.032
RF COIL VARIABLE	.0032	.023	.067	.20	.06	.044	.035	.064
RELAY	.14	.33	1.4	12	4.4	3.2	2.9	4.6
TOGGLE SWITCH	.0010	.0029	.014	.071	.029	.021	.021	.032
ROTARY SWITCH	.33	.96	4.6	23	9.6	6.9	6.9	11
COAX CONNECTOR	.0060	.017	.25	.43	.14	.10	.17	.19
PWB CONNECTOR	.0027	.024	.12	.21	.070	.05	.10	.091
2 SIDED BOARDS	.026	.062	.20	.78	.34	.23	.18	.36
MULTILAYER BOARDS	.14	.30	1.0	3.5	1.4	1.0	.30	1.6
CRYSTAL	.20	.20	.20	.20	.20	.20	.20	.20
LAMP INCANDESCENT	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

TABLE 2-13

GENERIC FAILURE RATE SUMMARY

GENERIC PART	GENERIC FAILURE RATE ($F/10^6$ HOURS)							
	N_S	N_{SB}	N_U	N_{UU}	S_F	U_{SL}		
RANDOM LOGIC < 100 GATES	.031	.031	.056	.045	.008	.080		
RANDOM LOGIC 100-2000 GATES	.[illegible]9	.09	.24	.10	.035	.18		
RANDOM LOGIC 2000-7500 GATES	.23	.23	1.0	.17	.10	.34		
RANDOM LOGIC 7500-20,000 GATES	.66	.66	3.0	.39	.33	.78		
ROMS < 2.2K BITS	.04	.04	.07	.05	.01	.09		
BIPOLAR ROMS 2.2K-17K BITS	.07	.07	.18	.08	.03	.15		
MOS ROMS 2.2K-17K BITS	.14	.14	.70	.11	.06	.21		
BIPOLAR ROMS 17K-74K BITS	.22	.22	1.1	.15	.10	.29		
MOS ROMS 17K-74K BITS	.35	.35	2.0	.19	.17	.41		
BIPOLAR RAM < 1.1K BITS	.13	.13	.45	.09	.07	.16		
BIPOLAR RAM 1.1K-5K BITS	.36	.36	1.4	.20	.22	.38		
MOS RAM 1.1K-5K BITS	.15	.15	.81	.10	.065	.20		
(MOS) RAM 5K-17K BITS	.91	.91	5.2	.38	.47	.85		
(MOS) RAM 17K-74K BITS	1.4	1.4	8.0	.56	.72	1.26		
LINEAR IC 1-32 TRANSISTORS	.045	.046	.17	.048	.013	.089		
LINEAR IC 33-100 TRANSISTORS	.11	.11	.54	.096	.037	.18		
LINEAR IC 101-300 TRANSISTORS	.32	.32	2.0	.19	.14	.40		
TRANSISTOR NPN	.026	.026	.098	.043	.001	.094		
TRANSISTOR PNP	.041	.041	.17	.068	.001	.14		
FET	.45	.31	2.0	.83	.028	1.8		
GEN PURPOSE DIODE	.0038	.0038	.035	.011	.0007	.027		
ZENER DIODE	.026	.026	.10	.049	.003	.10		
LED	.079	.05	1.5	.038	.007	.22		
MICROWAVE DETECTOR	2.2	1.6	8.7	10	.18	21		
MICROWAVE MIXER	3.0	2.2	15	14	.25	28		
MICROWAVE POWER TRANSISTOR	4.4	3.4	16	7.8	.79	19		
OPTICAL ISOLATOR	.89	.57	1.7	.43	.074	10		
RESISTOR, FIXED	.019	.015	.15	.024	.0025	.075		
RESISTOR, POWER	.4	.4	1.8	1.2	.11	2.6		
RESISTOR, TRIMMER	.086	.086	.31	.32	.014	.64		
CAPACITOR, MILAR, MICA	.012	.0092	.033	.03	.0021	.057		
CAPACITOR, CERAMIC	.061	.056	.15	.19	.0086	.36		
CAPACITOR, ELECTROLYTIC	.029	.026	.12	.078	.0045	.15		
VARIABLE CAPACITOR	2.8	2.8	16	7.9	.26	16		
PULSE TRANSFORMER	.019	.017	.078	.051	.0029	.10		
AUDIO TRANSFORMER	.038	.034	.16	.10	.0058	.20		
POWER TRANSFORMER	.14	.13	.84	.33	.021	.72		
RF TRANSFORMER	.15	.13	.62	.41	.024	.81		
RF COIL FIXED	.011	.010	.045	.029	.0016	.051		
RF COIL VARIABLE	.023	.020	.090	.058	.0032	.10		
RELAY	.88	1.4	4.0	4.5	.14	8.7		
TOGGLE SWITCH	.0057	.010	.020	.034	.0010	.06		
ROTARY SWITCH	1.9	3.3	6.6	11	.33	.21		
COAX CONNECTOR	.077	.059	.37	.14	.0060	.25		
PWB CONNECTOR	.040	.029	.20	.054	.0027	.12		
2 SIDED BOARDS	.14	.11	.34	.39	.026	.68		
MULTILAYER BOARDS	.63	.49	2.0	1.7	.14	3.2		
CRYSTAL	.20	.20	.20	.20	.20	.20		
LAMP INCANDESCENT	1.0	1.0	1.0	1.0	1.0	1.0		

TABLE 2-13

GENERIC FAILURE RATE SUMMARY

2.4 LOGISTICS SUPPORT SUBMODEL

This submodel takes as input the intrinsic failure rate (in $F/10^6$ hours) for each module type, the number of operating hours per year and the fielding profile. It estimates the induced failure rate and the effective fault group (as a function of BITE and intermediate level screening), such that the number of both faulty and "good" modules returned to the Repair Depot per year can be made available to the Cost-to-Repair Model.

2.4.1 Analysis of Induced Failures

Failures in electronic equipment modules/cards can be predicted and projected with reasonable accuracy based on the formulas given in MIL-HDBK-217. These projections have been proven over the past years to provide valid anticipated rates of failure and quantities of failed modules. They do not provide any allowance for other types of failures, such as those induced by other causes. Induced failures are caused by events outside the scope of normal operation of the equipment and its normal operating parameters and conditions. Generally, induced failures can be cataloged into one or more of the following categories/reasons:

(a) Outside introduced or induced circuit over-load or shock: may be sudden overload due to electrical storm, massive power surge, or the direct introduction to the circuit(s) due to improper connections.

(b) Improper handling: in this case, the improper handling is applicable to the whole unit or subunit, such as the dropping, banging, or other high impact to the equipment.

(c) Improper packing/shipping: subunits and sub-assemblies shipped or otherwise transported without proper and/or adequate packing causing damage in transit.

(d) Operator induced: mishandling of cards/modules in troubleshooting, testing, installation/removal, connecting of equipment, and/or control of power/signal levels.

(e) Maintenance induced: improper handling of cards/modules, improper test/test procedures, installation/removal damage, incorrect assembly/disassembly methods.

These variables do not provide for nice formulas and prediction procedures and methods, and sound data values are difficult to obtain. All available data upon which to base prediction values and formulas must be taken from reported data of systems in service which means that this information always lags current technology and methodology. Since no one likes to admit mistakes, all such data and past analyses are judgmental and somewhat arbitrary and conclusions must be based on knowledge and experience as well as those facts available. Many interpretations have had to be made in order to achieve any reasonable results.

Analysis of many groups of data, when evaluated against prediction failures, have shown that probably less than 30% of the actual induced failures have been reported as such. Those analyses performed have been able to identify sufficient cases and values to indicate that this is an approximate value and have had to work through various types of side factors to reach this conclusion. The samples of past historical data and analyses given below have been derived by many sources and provide some valid basis for a generalized prediction value.

Case 1: The Navy Standard Electronic Module Program performed a study that indicated that for every three SEM replaced in a system, one (1) was actually failed, one (1) became an "induced failure" for a variety of reasons, and one (1) was good. This gives us an induced failure rate of 100%, based on the number of actual failures.

Case 2: Analysis of two equipments utilizing custom modules, both having BITE capabilities, provided the data that: for a card size approximately 3" by 5", the induced failures equalled 35% of the actual failures; for a card size of approximately 5" by 5", induced failure rates were 30%. In both cases there was no intermediate facility involved, thus reducing one stage of handling and potential damage.

Case 3: A major military contractor performed an analysis of all of the failures in the plant's system test areas. The results showed that 25-30% of the total modules "failed" were induced failures caused by mishandling, improper installation and

removal procedures, improper troubleshooting methods, and carelessness. All of the responsible people were trained technicians and repair personnel.

Case 4: An analysis performed by a contractor operating an in-plant Repair Depot for several different equipments showed that 48% of the modules of all types and sizes returned for repair were damaged in some way. This damage was concluded to be due to reasons other than normal usage. The conclusions reached were that: 10% of the modules surveyed were damaged due to improper packaging and handling in shipping; 27% of the modules surveyed showed operator handling damage; 32% of the surveyed modules indicated actual or suspected induced circuit failures; some of the surveyed modules showed damage of more than one type. Of the surveyed modules, approximately 80% were processed through an intermediate facility, and their damage ratio was proportionally greater than those directly shipped.

Case 5: A major military contractor operating a field service support group for several major equipments surveyed its field technicians. These technicians provided data that is summarized in the following conclusions about module replacements and failures:

(a) In-process testing and troubleshooting of the equipments by the field technicians induced a 5% failure factor.

(b) 10% of all modules permanently replaced were due to "suspected failure" and "age".

(c) Operator/maintenance personnel, both on-site and at intermediate facilities, caused 21% of the failures and 7% of the physically damaged modules.

(d) 5% of all removed modules shipped or otherwise transported were not properly packaged or protected.

(e) BITE and/or fault location by equipment self-test was, at best, about 75% accurate even with "fault location" to a single module.

(f) Even when a module was replaced and failed to clear the "failure", 40% of the replaced modules were tagged as failures and not replaced in the equipment circuit.

(g) At least 30% of all of the personnel, both on-site and at intermediate facilities, lacked the necessary skills and training to properly handle all types of modules and to replace and troubleshoot them, especially if assembly and disassembly were required.

Based on the data cited above and the other data reviewed, an induced failure factor has been estimated. The fact that the data is based on older and less sophisticated systems and electronics than those now in production and use has been taken into consideration. Consequently, for this Cost Model the following conclusions and factors are stated:

(1) The factor used must include allowance for handling both on-site and at an intermediate facility.

(2) The value to be adjusted shall be the intrinsic failure rate for each module type, prior to any other adjustments to that value.

(3) The "Induced Failure Factor" shall be 40% of the predicted failure rate quantity for all module types and all functional categories.

2.4.2 <u>Analysis of Good vs Failed Modules Returned</u>

It is known that some of the modules returned for repair will be good (unfailed) modules that have been replaced due to the fault group size, undetermined faults, multiple module replacements, and LRU (lowest replacement unit - replacements where the LRU contains several modules and the failed ones are not isolated before returning for repair). Other factors also cause good modules to be replaced and returned, often because other factors have indicated module failure when it is not valid.

This analysis addresses the four (4) possible conditions that can exist in the field, i.e.: where no BITE/FL exists in the equipment and no intermediate screening; where BITE exists but no screening; where no BITE exists but there is screening; where both BITE and screening exist. Each of the functional categories is evaluated under each of these four conditions and is assessed for the impact of equipment size, i.e., a "small" system, a medium system, and a large system. A small system is considered as a man-portable or light vehicle, probably consisting of a total of three to twenty modules/cards.

A medium system may be fixed, trailer portable or vehicle mounted and is assumed to consist of more than one chassis as well as a larger quantity of modules/cards. A large system is considered to be a land based site, one or more trailers of equipment, etc. and to consist of several hundred modules/cards.

Intermediate facilities will be responsible for the return of modules to the Repair Depot. It is known that there will be different operations performed by these facilities, ranging from just packaging and shipping the supposedly failed modules to a complete screening/pretest where only those indicating failure are shipped for repair. Due to the cost of test equipment required to perform the tests on the modern modules of certain types, it is assumed that many of the modules cannot be completely tested, but at least some "go no-go" testing will be possible for most of the types. Where LRU's contain more than one module, the whole unit may end up being shipped back to the repair center especially if the intermediate facility cannot test beyond the complete unit level.

The major factors affecting the module replacement in the equipment that lead to the replacement of good modules are considered to be:

(1) Fault location capability of the equipment

(2) BITE capability and the size of the fault group

(3) Type of module function

(4) Size of the equipment

(5) Multiplicity of same module usage

(6) Number of modules/cards contained in an LRU

(7) Type of equipment functions

In addition to the above factors that cause good modules to be replaced in the equipment, the following factors determine whether or not all of those good modules are returned to the Repair Depot from the intermediate facilities.

(1) Availability of screening at the intermediate facility

(2) Effectiveness of the screening

(3) Module type/function

(4) Technological age of the equipment/circuitry

(5) Capabilities of the intermediate facility personnel

(6) Whether multiple module LRU's are returned whole or broken down to individual modules

Each functional category was evaluated against the above lists of factors, and estimated ratios of good modules to failed modules were developed for each case. A final average value was calculated for each of the four conditions based on an average of the three equipment sizes and the ratios of each.

MODULE ASSESSMENT BY TYPE:

Front End R-F

(a) Normally one of a kind, especially in small equipment

(b) BITE non-effective in small equipment, somewhat effective in larger systems

(c) Always encased units with complete unit; generally the LRU will contain multiple cards in larger units

(d) Estimated screening effectiveness at intermediate facility about 50%; not always available due to the RF equipment required

(e) Good module replacement low due to uniqueness of circuitry/function

RF-IF

(a) Normally few in quantity and one of a kind in small equipments

(b) May or may not be BITE effective

(c) Always encased units; may be multiple cards; unit is the LRU

(d) Estimated screening effectiveness at intermediate facility about 50%

(e) Good module replacement low due to uniqueness

Analog

(a) May be one or more cards in a circuit

(b) BITE/FL may not be effective

(c) Circuit/function not generally complex

(d) Screening effectiveness estimated at 75%

Power Supplies

(a) May be a module/card or a chassis unit

(b) BITE/FL to the LRU only

(c) May consist of multiple cards in larger units

(d) May be an encased unit requiring disassembly

(e) Screening effectiveness estimated at 80% when available

(f) Screeening may not be possible below the LRU level

Digital

(a) May be from one to many in any system

(b) May be capable of fault location to the module or to a circuit group, depending on equipment sophistication

(c) Circuit complexity varies from simple to very complex

(d) Technological age a factor in many cases

(e) Estimated screening effectiveness 50%

Digital Interface

(a) Will vary in quantity from one in small equipments to many in large systems

(b) BITE for fault location probably available; isolation to circuit probable

(c) Specialized circuitry causes higher complexity

(d) Screening effectiveness estimated at 40%, when possible

(e) Technology a definite factor in both screening and failure isolation

Memory

(a) Quantity variable by equipment size and type

(b) Multiple usage very likely

(c) BITE probable

(d) Circuit generally complex

(e) Screening effectiveness estimated as difficult (25%)

LSI

(a) Quantity variable by equipment size/type

(b) Circuitry complex, fault location difficult

(c) Technology a major factor in size, circuitry and failure isolation

(d) Screening effectiveness estimated at 25%, if even possible

The results of this analysis are presented in Table 2-14 in terms of a Screening Factor (SF) and Fault Group Factors (FGF) for with and without BITE for each Functional Category.

2.4.3 Logistics Support Submodel Summary

The number of failed modules of type i (N_{Fi}) returned to the Repair Depot per year is:

$$N_{Fi} = F_i N_i T N_S (1 + IFR)$$

And,

$$N_S = (D_E + D_B)/2$$

TABLE 2-14

SCREENING AND FAULT GROUP FACTORS

Functional Category	Screening Factor(SF)	Fault Group Factor (FGF) Without BITE	Fault Group Factor (FGF) With BITE
RF Front End	0.50	0.15	0.10
RF/IF	0.50	0.15	0.10
Analog	0.75	0.40	0.20
Power Supply	0.80	0.65	0.45
Digital	0.50	1.75	0.90
Digital Interface	0.40	1.50	0.90
Memory	0.25	1.50	0.45
LSI	0.20	1.50	0.75

Where:

F_i = Intrinsic failure rate of module i ($F/10^6$ hours)

N_i = Number of module i per system

T = System operating hours per year

D_B = Beginning-of-year density

D_E = End-of-year density

IFR = Induced failure factor (0.4)

The number of good modules of type i (N_{Gi}) returned to the Repair Depot per year is:

$$N_{Gi} = N_{Fi}\ FGF\ (1 - SF)$$

Where:

FGF = Fault Group Factor from Table 2-9.

SF = Screening Factor in accordance with Table 2-9 if intermediate level testing screening exists; otherwise, SF = 0.

The Failure Factor (FF_i) for module of type i in units of number of modules returned to the Repair Depot per year per 100 systems is:

$$FF_i = (N_{Fi} + N_{Gi}) \frac{100}{N_S}$$

SECTION 3.0

COST-TO-REPAIR MODEL

3.1 GENERAL

This analysis and study addresses the costing of electronic module Repair Depots to provide for the funding of a facility to repair and replace both damaged and failed electronic modules returned from in-service field equipments. It provides the cost estimating methodology and relationship values for projecting the total cost of operating, staffing and supporting a Repair Depot, and the cost of processing and repairing all returned modules. It is intended that this study will provide the means to project costs for this type of facility for all types of electronic equipment. Note that this study does not include nor address the costs for test equipment(s), intermediate depots/facilities operating between the in-service equipment sites and the Repair Depot, or handling/shipping costs.

3.1.1 Study Guidelines

Certain guidelines, as discussed below, have been established and were followed in the performance of this analysis. These guidelines, along with the stated assumptions, provide the basis for all of the cost methodology and relationships that were generated as the final output of the study.

(1) Costing generated by the methodology defined by this study shall be equally applicable to either a Government facility or a private industry contractor.

(2) All cost values shall be at a Total Cost Level (without fee) and shall be in FY 83 dollars. These costs shall be representative for all areas of the country and industry.

(3) All directly addressable and definable elements shall be given cost values, while all general and indirect elements shall be included as part of the overhead value.

(4) The Repair Depot's purpose shall be limited to the test, repair and disposition of returned modules that are damaged and/or failed, and shall not be considered as a Supply Depot.

(5) Modules dispositioned as "scrap" by the Repair Depot shall be replaced from "stock", and the cost of replacing these modules in "stock" is considered as a part of the Repair Depot's costs.

(6) Since space requirements are partially a function of manpower, all repair cycle elements shall generate manhour requirements for each work category, as well as costs in dollars, and these manhours shall be used to project floor space requirements.

(7) It shall be assumed that the quantities of modules are, in all cases, of great enough volume for the laws of averages to be valid in projecting costs, failures, and other

requirements. Moreover, a minimum volume of not less than one hundred (100) returned modules per year should be assumed, since it is estimated that a lower volume is not economically reasonable.

(8) All replacement parts shall be assumed to be new, and scrap modules shall not assumed to be used as a source of supply for repairs.

(9) Economic break-even points shall be used to make discard or repair decisions for modules. Where applicable in this costing, data and methodology for such decisions within the Repair Cycle shall be provided.

(10) Normal test and repair cycle work flow elements shall be assumed to be applicable for the Repair Depot and shall be used for the cost projections.

3.1.2 Definitions

It is important that special terms used in the generation of the costs and methodology be understood, and the definitions of most of the key terms are provided here.

FAULT GROUP - The size of the group of modules that is determined by the built-in test capabilities of the equipment. This group size is important because it determines the number of modules replaced for each equipment failure.

COMPLEXITY - A term used to categorize modules and electronic circuits into ranges varying from simple to very complex, depending upon a composite level of cost, difficulty and circuit integration. Further explanations of the various levels are provided in later sections.

FAILURE - A "failure" occurs when a module or electronic circuit does not provide all of its proper outputs, whether or not it has actually failed or not. Many "failures" are "apparent failures", when the equipment does not perform to requirements or the PM indicates failure.

REPLACED MODULE - A module replaced in the circuit of the equipment and believed to be defective.

FAILED MODULE - A module that does not meet performance requirements indicated by the various testing methods available, including modules visibly damaged.

RETURNED MODULES - Modules removed from operating equipments and sent to depots for test and repair.

REPLACEMENT MODULES - Modules carried in Depot Spares that are complete, operational and ready for installation. For this study, modules obtained from stock to replace those that have been designated as non-repairable and scrap.

PM - PM is the abbreviation for "performance monitoring", a built-in capability that monitors the equipment performance and indicates when the performance fails or falls below an acceptable level.

FL - FL is the abbreviation for "fault location", a built-in capability to isolate faults down to a certain group of modules.

BITE - An achronym for Built-in-Test Equipment to perform performance monitoring and/or fault location functioning.

INVENTORY - The stock of replacement parts carried in the Depot, in this case the Repair Depot, to be used to replace those parts found to be damaged and/or failed in returned modules.

SCRAP - Modules and parts that are damaged beyond repair and reuse; used to designate those returned modules that are not economically repairable, i.e., where the repair value exceeds the cost of providing a replacement.

CANNED MODULES - Modules whose cards, circuits and/or modules are contained inside metallic cases (cans), for both the physical protection of the units and the shielding of electronic emission.

OVERHEAD COST - Overhead costs are values of cost for various factors that cannot be clearly defined and assigned, yet are clearly required. These are indirect type efforts and services and are provided for by the application of factors to the known and/or calculated costs of direct costed elements. The normal method of defining these costs is to determine the ratio between all of the direct charged costs and the total costs, and is based on past performance and the projected future activities.

TEST, MANUAL - Manual testing occurs when the equipment used must be set up and adjusted manually for each step in the testing procedure with all changes and readings performed manually.

TEST, SEMI-AUTO - Semi-automatic testing occurs when the test equipment is set up and then performs part of the tests without the need for manual operations, but still requires some operator assistance and some direct manual operation.

TEST, AUTO - Automatic testing occurs when the unit to be tested is connected to the test equipment and all operations and results are performed and recorded by the equipment once it has been started.

TROUBLESHOOTING - This term is applied to the process of locating a failure in an electronic circuit, and determining what has caused the failure. The various levels and categories are the same as for TEST.

3.1.3 Rates, Conversion Factors and Formulas

The various rates, conversion formulas, factors and other data used throughout the Cost Model are provided below and will be referenced in the various sections of the test.

All costs used in this Model are at the "Total Cost Level", that is:

TOTAL COST = Base Rate x (1 + Overhead Rate) x (1 + G&A Rate)

Where:

Base Rate = actual dollars spent or actual salary paid

Overhead Rate, Labor - nominal value estimated at 120%

Overhead Rate, Materials - nominal value estimated at 20%

Materials Allowance Factor - estimated at 20%, includes all normal allowed allowances

Materials Factor =40% (material overhead+ materials allowance)

G&A Factor - nominal value estimated at 15%

Fee - no Fee factor has been provided since all costing is at Total Cost Level, and Fee is not applicable to Government facilities.

For private contractor/industry facilities, fee is an input parameter and can be estimated at 12% if not known.

All time is calculated in manhours (mhr). Note that:

Man-months = manhours/168

Man-years = manhours/2016

Labor Rates for all of the labor categories defined and used in this Cost Model are provided in Table 3-1. Each of the Rates is provided with a Reference Number, a Classification Description, an Hourly Rate Code, and Cost Values. The Rate Cost Values are given in Base Rate Per Hour, the actual estimated rate that is paid to the person, but all other values which are used in the Cost Model formulas are given in Total Cost Dollars.

TABLE 3-1

HOURLY LABOR RATES BY CLASSIFICATION (FY83 $)

REF. NO.	CLASSIFICATION	HOURLY RATE CODE	BASE RATE PER HOUR	$ PER HOUR	$ PER DAY	$ PER WEEK	$ PER MONTH	$K PER YEAR
1	MANAGEMENT - MANAGER	MM1	$20.00	50.00	400	2000	8400	100
2	MANAGEMENT - SUPPORT	MS1	15.00	38.00	300	1500	6400	77
3	ENGINEER	EE1	18.00	45.00	360	1800	7600	90
4	TEST EQUIPMENT - ENG'G.	TE1	14.00	35.00	280	1400	5900	71
5	TEST EQUIPMENT - FLOOR	TE2	12.00	30.00	240	1200	5000	60
6	PROD.CONT. - SCHED./REPORT - INVENT. CONT.	PC1	12.00	30.00	240	1200	5000	60
7	PROD.CONT. - EXPEDITE - STOCK/INVENT.	PC2	7.00	18.00	144	720	3000	36
8	TEST TECH.	TT1	10.00	25.00	200	1000	4200	50
9	INSPECTION - INITIAL	QC1	8.00	20.00	160	800	3400	40
10	INSPECTION - FINAL	QC2	7.00	18.00	144	720	3000	36
11	REPAIR/ASSEMBLY	RA1	8.00	20.00	160	800	3400	40
12	REPAIR/ASSEMBLY/TOUCHUP	RA2	6.00	15.00	120	600	2500	30
13	REC'G./PACK/SHIP	RS1	6.00	15.00	120	600	2500	30

<u>NOTE:</u> These rates are rounded values for convenience in calculations.

All costing in this Cost Model is provided for in FY 83 dollars. The current DOD Tables of Escalation Factors should be used when costs other than baseline are required.

These cost and rate values are country-wide averages, and may differ from those in a specific locale. Labor categories for repair personnel are about two steps higher than the normal factory grade for the equivalent work. Higher level of skill is needed due to the varied complexity and mix of work to be performed and the other unknowns that must be dealt with. Non-hourly types of labor are costed at general average rates that are considered to be a composite of levels required for the tasks.

3.1.4 *Functional Category Descriptions*

This Cost Model addresses eight (8) electronic module categories, assuming that all possible modules can be assigned to one of these categories. The actual assignment of each module is part of the input process, but the definition of the module type, as addressed by the Cost Model, is provided here with the various characteristics of each type.

RF Front End

(1) Non-standard size/shape, mixed component types

(2) Shielded circuitry: canned elements and modules; packaged units

(3) Tuned and tuneable components

(7) Final testing will probably require some circuit tuning

(8) Disassembly/assembly probably required for most modules

(9) Circuit card density low to medium

(10) Probable defective components 1 to 3

(11) Varied component technologies and types

(12) Anticipate 35% visibly damaged; 65% other

<u>Analog</u>

(1) Non-sophisticated circuitry, components

(2) Probably some adjustable components

(3) Testing may be manual, semi-auto or auto

(4) Troubleshooting will not be auto

(5) Testing/troubleshooting probably simple to medium complexity with the average being simple

(6) May or may not be plug-in module

(7) Circuit card density - medium

(8) Probable defective components 1 to 4

(9) Circuit technology will be varied and may be analog, digital or mixed

(10) Anticipate 35% visibly damaged; 65% other

<u>Power Supply</u>

(1) Mixed circuitry and component types

(2) May be plug-in or wired-in module

(4) Module cards possible hardwired; use external leads; coax connectors

(5) No automatic testing; all manual and/or semi-auto

(6) Testing/troubleshooting will be manual and/or semi-auto and to range from medium to very complex, depending on size factor; average estimated to be medium complexity range

(7) Final testing probably will require some circuit tuning

(8) Disassembly/assembly is required for most modules

(9) Circuit card density is low to medium

(10) Probable defective components 1 to 4

(11) Component technology will probably vary widely

(12) Anticipate 30% visibly damaged; 70% other

RF/IF

(1) Non-standard size/shape; mix of component types

(2) Shielded circuitry; canned elements and modules; packaged units

(3) Tuned and tunable components; frequency sensitive

(4) Mechanical components; hardwiring on modules; shielding

(5) No automatic testing; all manual and semi-auto

(6) Testing/troubleshooting will be manual and/or semi-auto and to range from medium to very complex, depending on size factor, with medium complexity as average

(3) Disassembly/assembly may be required; however, normal module received shall assume no assembly requirement

(4) Test/troubleshooting may be manual, semi-auto or auto

(5) Complexity range medium to complex; average estimated as medium

(6) Circuit card density low to medium

(7) Component technology varied but not highly sophisticated.

(8) Probable defective components 1 to 3

(9) Anticipate 40% visibly damaged modules; 60% other

Digital

(1) Components simple to very complex

(2) Some modules may require disassembly/ assembly; however, majority will not and this category shall assume no assembly

(3) Components mainly integrated circuits

(4) Test/troubleshooting may be manual, semi-auto or auto

(5) Modules range from simple to very complex; average estimated as simple

(6) Circuit cards mainly plug-in

(7) Circuit card density medium to very high

(8) Probable defective components 1 to 3

(9) More complex types included in specific categories

(10) Anticipate 30% visibly damaged; 70% other

(11) More complex modules will require multi-layer boards

(12) High scrap rate in lower complexity modules; lowers as value increases

Digital Interface

(1) Mixed circuitry, analog, digital D/A, D/S, etc.

(2) Mixed component types, sizes

(3) Components medium to very complex with average being medium complexity

(4) Module complexity medium to very complex

(5) Test may be manual, semi-auto or auto

(6) Troubleshooting may be manual or semi-auto, very few auto

(7) Most circuit cards are plug in

(8) Circuit card density medium to very high

(9) Probable failed/defective components 1 to 3

(10) About 25% modules visibly damaged, 75% other

(11) More complex modules will require multi-layer boards

Memory

(1) Circuits highly integrated; multi-function

(2) Complexity range is complex to very complex; size is a factor, but average will be complex

(3) Test/troubleshoot semi-auto or auto; no manual

(4) Troubleshooting may have to be by parts replacement in some cases

(5) Probably multi-layer boards for most modules

(6) Circuit board components density high

(7) Circuit cards mostly plug-in

(8) Probable failed/defective components 1 to 3

(9) Visibly damaged about 30%; 70% other

LSI

(1) Circuits highly integrated, multi-function

(2) Complexity range is complex

(3) Test/troubleshooting semi-auto or auto; no manual

(4) Troubleshooting may require parts replacement

(5) Probably multi-layer boards for all modules

(6) Circuit board density very high

(7) Circuit cards mainly plug-in

(8) Probable failed/defective parts 1 to 4

(9) Expect about 25% visibly damaged; 75% other

3.2 COST MODEL SUMMARY

This Cost Model is designed and developed to work with a minimum amount of input data, most of which is provided by outputs from the Failure Rate Model. It is designed to provide outputs of Depot costs, manpower requirements, and space requirements for the level of activity set by the number of modules returned for processing through the Depot. These costs and other requirements have been determined to fall into four (4) separate task areas, and each is addressed separately in the Cost Model,

with the final results showing a total for each. These areas are: repair operations, management and support, materials costs, facilities costs.

Final Model Output

Total repair costs	\$ xxxx
Total management & support	\$ xxxx
Total materials cost	\$ xxxx
Total facilities costs	\$ xxxx

Total Costs @ TCL (base year)	\$xxxxx
Escalation Factor @ xx%	\$xxxxx
Management Reserve @ xx	\$ xxxx

Total Adjusted Costs @ TCL	\$xxxxx
Fee (if applicable) @ xx%	\$ xxxx

Total Depot Costs	\$xxxxx

Manpower

Total Repair Operations, by labor category	ZZZZ mhr
Total Management & Support, by labor category	ZZZZ mhr

Total manpower	ZZZZ mhr

Facilities/Space

Repair operations space	YYYY sq. ft.
Management space	YYYY sq. ft.

Total space	YYYY sq. ft.

The outputs shown above are the final results, and all of the backup for each of the cost areas is shown and explained in separate sections following this section. The flow of information into this Model and the outputs derived by it are given in the Flow Diagram, Figure 3-1.

COST MODEL FLOW DIAGRAM

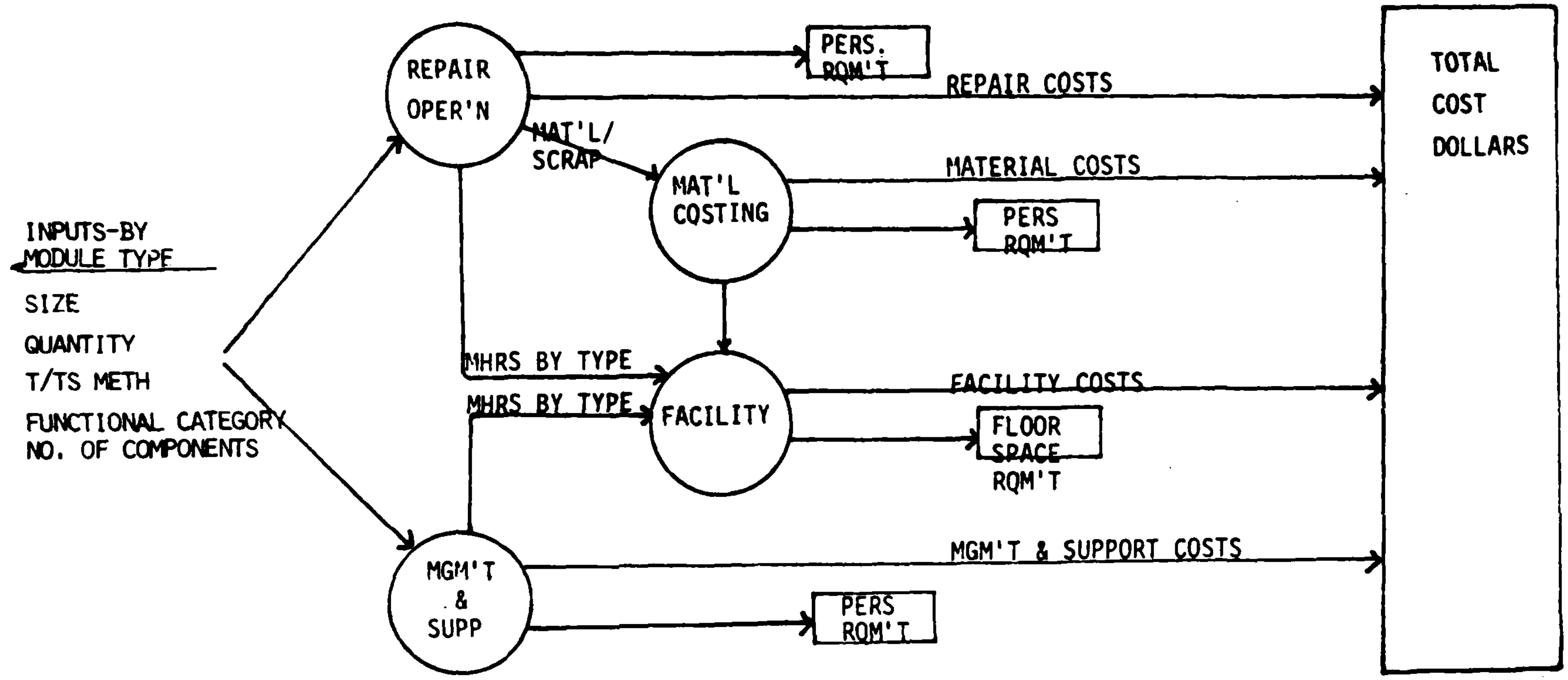


FIGURE 3-1

3.3 REPAIR CYCLE OPERATIONS COSTING

This section describes and explains the events, requirements and costing methods for the operations required in the Repair Cycle of the returned modules. It provides descriptions of the operations, the work performed, the labor used and the various assumptions that have to be made. Detail and rationale of the tasks, factors used in deriving the formulas, etc., are contained in herein. This section describes the events shown in Figure 3-2, the Module Repair Flow Diagram.

3.3.1 Repair Cycle Cost Assumptions

Certain values and information must be either provided or assumed in order to develop costing methodology. These are the assumed values and guidelines that are used and followed in developing this portion of the Cost Model.

It is assumed that:

(1) All returned modules are categorized correctly by size and type

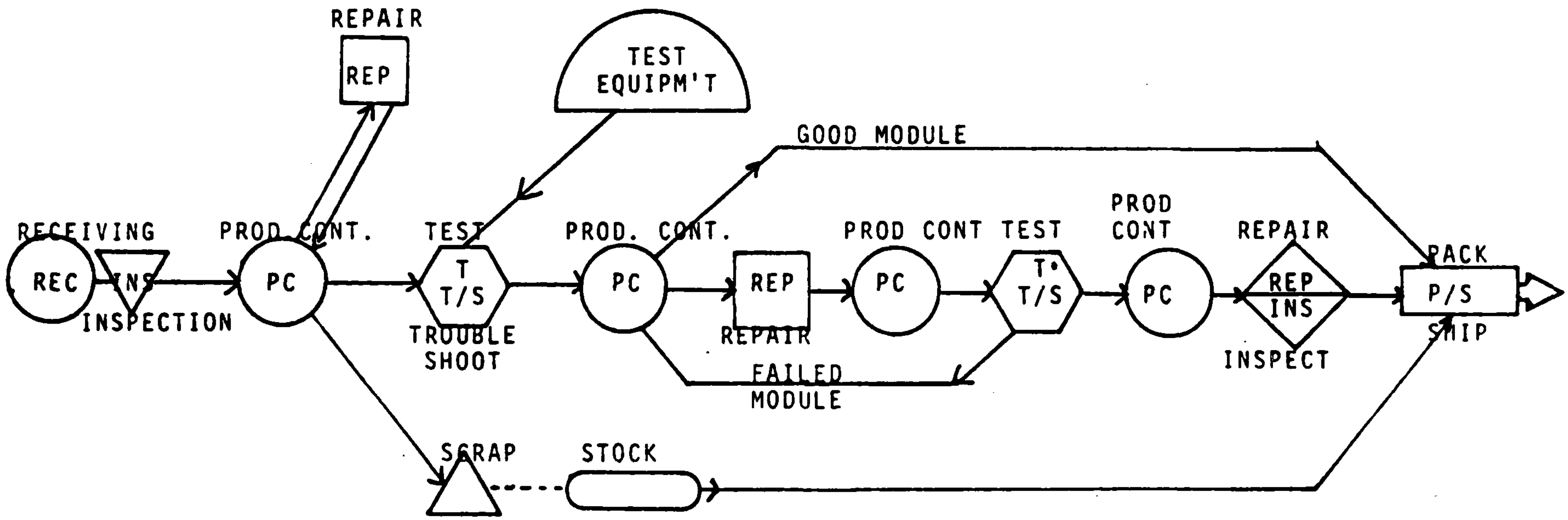
(2) All module quantities are given for each type

(3) All module complexities are calculated as a function of inputs

(4) The area of the smallest modules will be no less than three (3) squared inches

(5) The fewest components on any module will not be less than three (3)

MODULE REPAIR CYCLE FLOW



NOTE: REPAIR FLOW SHOWN IS TYPICAL, BUT SOME STAGES NOT SHOWN WHERE NOT CRITICAL.

FIGURE 3-2

(6) All required replacement parts are available in stock when required

(7) All modules have a normal component density, and those that do not conform have been size adjusted accordingly

(8) All test and other special equipment is provided and available from stock, and all necessary drawings, specifications and other documents are available from Depot files when required

(9) All repair facilities utilize approximately the same procedures and work flow regardless of the titles that may be given to any stage or event or task in the repair process

(10) All hours generated in this Cost Model provide adequate Allowed Time for any facility, regardless of their particular mark-up to Standard Time

(11) No module will be allowed to recycle in the process more than twice after the initial test and troubleshooting

(12) All modules are evaluated for Repair/Scrap disposition at the first major step in the Production Control Cycle.

3.3.2 Repair Operation Definitions

There are specific elements in the repair operations that must be understood, and the following definitions are provided to clarify key elements.

Returned Modules - All modules returned to the Repair Depot, whether good or bad.

Visibly Damaged - Modules that are damaged in some manner to the extent that the damage is visible to the eye and can be defined.

Good Modules - Modules that are returned as "failed" but are not visibly damaged and meet all requirements when tested.

Scrap Modules - Modules that are damaged beyond repair, or modules with repair costs that exceed the cost of replacement and thus are not economical to repair.

Direct Labor - That labor which is definable to any individual module and is required for that module, usually labor that must actually touch and work on the module.

Indirect Labor - That labor which provides general support, does not usually touch the module, and is required but not for every module.

Repair Category - The particular grouping into which the module is placed due to the repair/test requirements, essentially an arbitrary grouping used for costing projections and purposes.

3.3.3 Repair Operating Categories

Category 1: Visibly Damaged - All modules in this category are defective since they are visibly damaged and must be repaired. There are three (3) sub-categories for these modules.

(1) Visible Damage - non-repairable, scrap

(2) Visible Damage - repair, test good

(3) Visible Damage - repair, test failure, repair, test good

Category 2: No Visible Damage - All modules in this category do not show damage and must be tested to determine the failure status. There are five (5) sub-categories for these modules.

(1) Test - good - return to stock

(2) Test - troubleshoot - failure disposition - scrap

(3) Test - troubleshoot - repair - test good

(4) Test - troubleshoot - repair - test bad - trouble-shoot - repair - test good

(5) Test - troubleshoot - repair - test bad - troubleshoot - repair - test bad - trouble-shoot - repair - test good

Analysis of the inspection/test reports of some of those modules returned to the Repair Depot will result in a disposition of non-repairable, scrap and replace. This decision and disposition will be made for the following reasons, as well as others:

(1) When the cost-to-repair exceeds the costs of a replacement module.

(2) When visible inspection or test indicates that the circuit board requires replacement.

(3) When the cost of test and troubleshooting exceeds cost of a replacement module.

(4) When the module condition and/or function cannot be restored to a satisfactory level even with repair.

(5) When obsolescence makes parts unavailable and a redesigned circuit is available.

Table 3-2 shows the estimated projected percentage values for each of the repair categories for each module type. Based on the quantities of failed modules, these values are used in the formulas to calculate repair costs and the requirements for manpower. Column 2a in this table indicates a percentage value for good modules returned with the failed modules. This is not shown here since it is a variable value calculated as an addition to the quantity of failed and returned modules. It is variable since it depends on one of four conditions; namely,

TABLE 3-2

MODULE FAILURE: DISTRIBUTION RATIO BY TYPE

		VISIBLY DAMAGED			NO VISIBLE DAMAGE				
MOD. CODE	MODULE CATEGORY	1(a) SCRAP	1(b) REP,OK	1(c) REP/REP	2(a)[1] GOOD	2(b) NG-SCRAP	2(c) REP,OK	2(d) REP,X2	2(e) REP,X3
A	R-F FRONT END	5%	10%	15%	(1)	10%	40%	15%	5%
B	RF/IF	10%	10%	15%	(1)	10%	35%	10%	10%
C	ANALOG	5%	15%	15%	(1)	15%	35%	10%	5%
D	POWER SUPPLY	10%	15%	15%	(1)	10%	35%	10%	5%
E	DIGITAL	10%	10%	10%	(1)	15%	40%	10%	5%
F	DIGITAL INTERFACE	5%	10%	10%	(1)	15%	45%	10%	5%
G	MEMORY	10%	10%	10%	(1)	10%	45%	10%	5%
H	LSI/MP	5%	10%	10%	(1)	15%	45%	15%	-0-

[1] These values will be calculated and provided as part of the input from the interface formulas, based on the stated equipment status and module types.

BITE, no BITE, screening, no screening. These are input data that will select which of the four conditions and data to be applied in the interface calculation to determine total modules returned for repair.

3.3.4 Repair Cycle Stages: Description and Costing

Figure 3-3 provides a simplistic diagram of the flow through the repair cycle and the various operations that are included in the cycle, as well as very brief descriptions of the work performed in each of the stages. A more complete and detailed step-by-step description is provided in following paragraphs.

Two types of labor are required in the repair operations, consisting of the direct labor actually performing the work and the indirect labor providing support for all of the direct efforts. The indirect includes such labor efforts as supervision, quality control, facilities and maintenance, process and methods engineering, equipment set-up and support, etc. All of the indirect labor is costed as part of the overhead, since it cannot be specifically identified to any single module. The direct labor categories are those shown in Figure 3-3.

FIGURE 3-3

REPAIR CYCLE STAGES

RECEIVING:	Receive all returned modules; record and initiate paperwork; forward to Incoming Inspection
INSPECTION:	Visually inspect all modules; record any damage and initiate repair order; forward to Production Control
PRODUCTION CONTROL:	Schedule into the repair cycle; review Inspection report for possible "scrap" disposition; forward to either Repair or Test; if Repair, forward required parts
INITIAL TEST:	Test for proper performance; if failed, troubleshoot to determine failure; record findings and designate further operations required; return to Production Control
PRODUCTION CONTROL:	Schedule repair; obtain parts required and forward to Repair; if module is good, forward for processing to return to Stock
REPAIR:	Repair module in accordance with repair order; return to Production Control for further disposition of parts and forwarding to Test. (These operations are repeated until module is accepted)

FIGURE 3-3

REPAIR CYCLE STAGES (continued)

RETEST:	Test module for proper performance. If good, complete test report. If failed, troubleshoot to determine failure and repair; list repair on order in all cases, return to Production Control for further disposition. (These operations are repeated until module is accepted)
REPAIR:	This is final repair operation; module is cleaned, repaired for cosmetic appearance, coating is restored; returned to Production Control
PRODUCTION CONTROL:	Complete all paperwork; verify all test/repair sheets; initiate shipping papers and forward to Shipping; complete repair report and file
PACK/SHIP:	Complete shipping papers; pack for shipping; ship to Stock.

Other support for the repair operations is provided as part of the Management and Support tasks and is costed separately from these efforts. The only effort not included here that is a direct part of the repair support is the task of maintaining the stock room and stock/supplies of parts. This is included in the final formulas that sum up all of the repair costs.

All returned modules are processed through the Repair Cycle and must be processed through some of the stages but not necessarily all of them. Figure 3-3 showed a brief overview of the various stages and the operations; these are now fully defined as follows:

(1) Receiving:

Task - Each module arriving at the Depot is sent to Receiving where it is unpacked, a set of documents is initiated listing all of its pertinent data and any special notations. This paperwork will stay with the module until it has completed all of its stages in the repair cycle and will then be filed.

Cost - The cost of this stage is a constant and is based on an averaged value for all modules, with five minutes allowed for unpacking and storage and ten minutes for paperwork: a total of fifteen minutes. Cost value is: 0.25 mhr.

(2) Inspection, Incoming:

Task - Each module is sent from Receiving to Inspection where it is given a complete visual inspection for all physical characteristics and for evidence of breakage, damage and other defects. All results and findings are recorded on the module's documents, and the Repair Order is initiated. The module is then forwarded to Production Control.

Cost - Inspection costs consist of both a constant and a variable value, described as follows, and calculated by a given formula.

(a) Constant Value - To initiate the Repair Order, report the inspection findings and perform a basic inspection. The estimated value is: 0.15 mhr.

(b) Variable Value - The variable is based on the number of components on the module that must be inspected. The estimated time is 0.02 mhr per component.

Cost Formula: $0.15 + (0.02 \times C)$

(3) Production Control

At this point, Production Control receives all modules and is responsible for them until all necessary stages have been completed and the final disposition or shipping of the module takes place. There are a multiplicity of different tasks performed by this function, each of which is described separately when applicable.

Staging:

Task - Each module is recorded in the system and must be scheduled into the repair cycle and followed through all of the necessary steps.

Cost - The cost of this event is constant, and it is estimated to be a value of: 0.35 mhr.

Alternate Additional Tasks:

These steps are taken on an either/or basis.

(a) Scrap:

Task - When the module is received and it is determined that is is not repairable, it is dispositioned as "scrap". In this case a replacement module must be obtained from stock and forwarded for shipment to replace the returned module and the scrap module must be processed and dispositioned.

Cost - The cost for these tasks is estimated to be 0.35 mhr.

(b) Repair:

Task - When the module is received and is to be repaired, the necessary replacement parts must be obtained from stock and forwarded, with the module, to the Initial Repair Station.

Cost - The estimated time for these tasks is: 0.20 mhr.

(c) Test:

Task - When the module is received and test is indicated, it is forwarded to the 1st Test Station.

Cost - The estimated time for these tasks is: 0.15 mhr.

NOTE: For either 3(b) or 3(c), Test Equipment is notified and the necessary action to setup for module testing is initiated.

(4) Initial Repair

Task - At initial repair, damaged and/or broken parts are replaced and other visible damage is repaired. For those modules that require it, the module is disassembled sufficiently for repair and/or parts access during the testing and troubleshooting stages.

Cost - Costs for this event are estimated as constant value; however, there are two (2) cost values depending on the work to be performed and determined by module type. In estimating the costs, an average value has been determined that assumes that more than one part may require replacement, thus the value is really for 1.5 parts. The disassembly cost is estimated to be an averaged value of 0.10 mhr each, even though this is known to be variable because of size.

(a) Repair cost, no disassembly = 0.25 mhr.

(b) Repair cost, with disassembly = 0.25 + 0.10 = 0.35 mhr.

(5) <u>Test Equipment Setup</u>

Test equipment technicians are required to check out all of the required equipment, set it up in readiness for the module testing and troubleshooting, and provide all of the necessary test documents with the equipment. This task will vary depending on the type of testing method and equipment used and also the method for troubleshooting. Each of the possible methods is costed separately, and they are divided into six (6) separate categories:

<u>Cost</u>:

(a) Manual test/troubleshoot - estimated time = 3.0 mhr.

(b) Semi-auto test and troubleshoot - estimated time = 2.0 mhr.

(c) Semi-auto test and manual troubleshoot - estimated time = 3.0 mhr.

(d) Auto test and troubleshoot - estimated time = 1.0 mhr.

(e) Auto test/semi-auto troubleshoot - estimated time = 2.0 mhr.

(f) Auto test/manual troubleshoot - estimated time = 3.0 mhr.

(6) Production Control:

Task - This stage is only for those modules that were sent to initial repair. When complete, module is sent to this stage where it is forwarded to 1st Test and the replaced parts are dispositioned.

Cost - The estimated cost for this stage is: 0.20 mhr.

(7A) 1st Test:

Task - Test each module per its performance specification to determine that it is either fully functioning or defective. If good, return to Production Control; if defective, troubleshoot and locate failure.

Cost - The cost of testing is determined by the number of components, the type of testing, and the complexity of the module. It consists of a basic fixed value and a variable in all cases. Refer to Table 3-3 for allowable test method assignments and module complexity definitions.

(a) Auto test:

Simple - $.05 + C(.02355\ C^{-0.34666})$

Medium - $.05 + C(.05102\ C^{-0.40159})$

Complex - $.05 + C(.08232\ C^{-0.39772})$

TABLE 3-3

MODULE COSTING FACTORS

MODULE TYPE	TEST	TROUBLE	COMPLEXITY	DENSITY	REPAIR
RF Front End	S,M	S,M	MED	LOW/MED	Disassembly
RF/IF	S,M	S,M	MED	LOW/MED	Disassembly
Analog	A,S,M	S,M	SIM	LOW/MED	No Disassembly
Power Supply	A,S,M	A,S,M	MED	LOW/MED	No Disassembly
Digital	A,S,M	A,S,M	SIM	MED/HIGH	No Disassembly
Digital Interface	A,S,M	A,S,M	MED	MED/HIGH	No Disassembly
Memory	A,S	A,S	COM	MED/HIGH	No Disassembly
LSI/Hybrid	A,S	A,S	COM	HIGH	No Disassembly

(b) Semi-auto:

Simple - $.10 + C(.03471\ C^{-0.37240})$

Medium - $.10 + C(.08314\ C^{-0.42196})$

Complex - $.10 + C(.11276\ C^{-0.38387})$

(c) Manual:

Simple - $.12 + C(.04287\ C^{-0.31201})$

Medium - $.12 + C(.11575\ C^{-0.43526})$

Complex - $.15 + C(.18566\ C^{-0.44735})$

(7B) 1st Troubleshoot:

Task - Troubleshoot each module that fails to meet all of the performance requirements to locate defective and/or failed component(s) or other module defects causing the failure. Findings are recorded for repair. If necessary, suspect components may be removed and replaced with known good components to determine operability and performance. The type of troubleshooting will partially depend upon the type of module testing.

Cost - The cost of troubleshooting is determined by the number of components, the module complexity, and the method of testing and troubleshooting used. It consists of a fixed basic value and a variable in each case. Refer to Table 3-3 for allowable troubleshooting assignments and module complexity definitions.

AD-A146 509   ANALYSES TO DEVELOP MODELS TO PROJECT FAILURE RATES AND   2/2
REPAIR COSTS OF ELECTRONIC MODULES AND SUBASSEMBLIES
(U) AGORA SYSTEMS INC GAITHERSBURG MD   21 SEP 83
UNCLASSIFIED   DAAB07-82-C-Q004   F/G 9/5   NL

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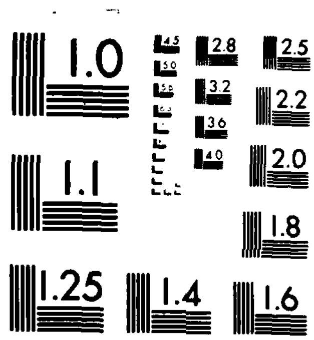

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

(a) Auto:

Simple - $.05 + C(.02892\ C^{-0.34770})$

Medium - $.05 + C(.05784\ C^{-0.34770})$

Complex - $.05 + C(.08276\ C^{-0.34364})$

(b) Semi-auto:

Simple - $.08 + C(.03852\ C^{-0.32774})$

Medium - $.08 + C(.03852\ C^{-0.32774})$

Complex - $.10 + C(.10063\ C^{-0.32774})$

(c) Manual:

Simple - $.10 + C(.05099\ C^{-0.23286})$

Medium - $.10 + C(.10198\ C^{-0.23286})$

Complex - $.12 + C(.13639\ C^{-0.22403})$

(8) Production Control

This stage in Production Control receives the modules from Test or Troubleshoot and makes one (1) of three (3) dispositions.

(a) Module "Good":

Task - Module has passed performance tests; process documents and forward module to Final Repair/Touchup if it has been repaired or Pack/Ship if it has just been tested.

Cost - Estimated time for these tasks is: 0.20 mhr.

(b) <u>Module</u> <u>"Scrap"</u>:

<u>Task</u> - Module has failed test, and the troubleshoot analysis review indicates non-repairable either due to type of failure or excess cost. Obtain a replacement module from stock and forward to Pack/Ship, disposition failed module as Scrap, and process all necessary documents.

<u>Cost</u> - Estimated time for these tasks is: 0.35 mhr.

(c) <u>Module</u> <u>"Failed"</u>:

<u>Task</u> - Obtain the required replacement parts from stock and forward module to Repair.

<u>Cost</u> - Estimated time for these tasks is: 0.20 mhr.

(9) <u>Repair</u>:

<u>Task</u> - Repair module in accordance with the Repair Order.

<u>Cost</u> - Estimated time to perform the necessary repairs will be based on the assumption that only one (1) part is to be replaced or one (1) repair must be made. Time allowed (average) will also depend on the need for assembly/disassembly or not.

(a) With assembly/disassembly, estimated time is: 0.17 + 0.10 = 0.27 mhr.

(b) Without assembly/disassembly, estimated time is: 0.17 mhr.

(10) Production Control

Task - At this stage, Production Control receives module from repair, forwards it to 2nd Test, and dispositions any parts replaced.

Cost - Estimated time is a constant at: 0.20 mhr.

(11A) 2nd Test

Task - This task is the same as 1st Test and requires all of the same steps.

Cost - Costs will be the same as in 1st Test, and the same formulas shall be applicable for each module type.

(11B) 2nd Troubleshoot

Task - This task is the same as 1st Troubleshoot.

Cost - Costs are the same as 1st Troubleshoot, and the same formulas shall be applicable.

(12) <u>Production Control</u>

This stage receives the module from either Test or Troubleshoot and processes it forward, depending on the disposition of the module as shown below.

(a) <u>Module</u> <u>"Good"</u>:

<u>Task</u> - Forward module to Final Repair/Touchup with documents.

<u>Cost</u> - Estimated constant time is: 0.10 mhr.

(b) <u>Module</u> <u>"Failed"</u>:

<u>Task</u> - Obtain the required replacement parts from stock and forward with module to Repair.

<u>Cost</u> - Estimated time for these tasks is: 0.20 mhr.

(13) <u>Repair</u>: (2)

The tasks and costs for this stage are the same as described in Stage 9. The costs are shown below:

<u>Cost</u>:

(a) With assembly/disassembly, time is: 0.17 + 0.10 = 0.27 mhr.

(b) Without assembly/disassembly, time is: 0.17 mhr.

(14) Production Control:

This stage is exactly the same as described in Stage 10, and the costs are shown the same.

Cost - Estimated time is: 0.20 mhr.

(15A) 3rd Test:

This stage is a repeat of Stage 11A, and all tasks and cost formulas are the same.

(15B) 3rd Troubleshoot:

This stage is a repeat of Stage 11B, and all tasks and cost formulas are the same.

(16) Production Control:

The tasks for this stage are the same as in Stage 12, and the same two alternatives exist. The costs for the tasks are also the same and are shown below:

(a) Module "Good": Estimated time is: 0.10 mhr.

(b) Module "Failed": Estimated time is: 0.20 mhr.

(17) <u>Repair</u>:

The tasks and costs for this stage are exactly the same as Stage 13. The cost times are shown below:

(a) With assembly/disassembly, time is: 0.17 + 0.10 = 0.27 mhr.

(b) Without assembly/disassembly, time is: 0.17 mhr.

(18) <u>Production Control</u>:

The tasks and costs at this stage are the same as at Stage 14.

<u>Cost</u>: Estimated time is: 0.20 mhr.

(19) <u>Final Test</u>:

<u>Task</u> - This is assumed to be the last time that the module will be tested since only three (3) cycles are allowed. The total performance of the module is tested and recorded, and all of the documentation is completed.

<u>Cost</u> - Estimated costs, times and formulas are the same as shown in Stage 7A and should be used as applicable.

(20) Production Control:

Task - At this stage the module has passed Test and is now forwarded to Final Repair/Touchup for cosmetic, marking and coating repairs. All documentation is sent with the module at this time.

Cost - Estimated time for this task is: 0.10 mhr.

(21) Final Repair/Touchup:

At this final stage all of the cosmetic, marking and cleanliness work is performed to restore the module to as close as "like new" condition as is possible. The module is fully reassembled and passed through a final inspection process (performed separately) in readiness for shipment. All protective coatings are restored and/or repaired in accordance with the module's requirements. Costs for this stage are directly proportional to size, and this is reflected in the costing formula.

Task - Clean, restore markings, cosmetic appearance and coatings to "like new" conditions (if possible), reassemble as required, and send through final inspection.

Cost - The time to perform the above tasks is based on the size of the module, since all of the above tasks are performed on each module. It is estimated that the minimum time required is .15 mhr for a 3 in^2 module, and .50 mhr for the largest module, assumed to be 144 in^2. All modules are assumed to require some amount of reassembly, so the module type is not

factored at this stage. The following formula is used to provide a total time required, based on the module size in square inches (in^2).

Formula: Repair time = .142553 + (.002482 x S)

Where:

S = module size in inches squared

(22) Inspection, Final:

Task - At this stage the module has been cleaned, touched up, remarked and is either fully reassembled or ready for the final assembly depending on the module. Inspection of all of the module is performed to ensure that it meets all of the applicable requirements and specifications.

Cost - The time to perform the inspection is based on a fixed value for all modules to provide for the necessary documentation, a minimum number of components, and module area; this value is estimated at 0.15 mhr. The variable cost is dependent on the module size and number of components and is estimated at .01 mhr per component.

Formula: 0.15 + (.01 x C) = mhr

Where:

C = component quantity

(23) Production Control:

This is the final operation in the Production Control cycle, and all tasks are now completed in the normal module repair cycle.

Task - Receive module from last operation, process all of the documentation, send module to Pack/Ship with shipping instructions, and complete all necessary records and reports.

Cost - The estimated time for these tasks is: 0.20 mhr.

(24) Pack/Ship:

Task - Receive module, pack for shipping in accordance with the appropriate instructions, label, and ship to destination. Send shipping copies to records.

Cost - The time estimated for this stage is in two parts: the estimated time to pack, which is 0.17 mhr and the estimated time to make out the shipping papers, labelling and the actual shipping process as well as the recording(s), which is 0.25 mhr.

Total time = 0.17 + 0.25 = 0.42 mhr.

(25) Test Equipment - Store:

Task - When the module has completed the cycle and is shipped, all test equipment required for test and troubleshooting is returned to storage with any documents and drawings that may have been furnished. The times required are based on the type of equipment that was used.

Cost - The following estimated times are provided for this task:

(a) Auto test - 0.17 mhr

(b) Semi-auto test - 0.25 mhr

(c) Manual test - 0.40 mhr

INVENTORY/STOCK CONTROL

This is the activity required to maintain the stock room, to issue the various replacement parts and modules, process all of the various parts requests, and requisition and restock the inventory. These tasks are not a direct part of the Repair Cycle but a support for its operation. Part of the costs are carried in overhead, but the direct work is chargeable to each module based on the support provided. Each module that passes through the Repair Cycle requires some support so cost can be determined by the amount of support required.

Cost - The following formula for the time to support module repair is based on estimates that project that each part ordered takes three (3) minutes to process, each part issued takes five (5) minutes to issue, document and restock, and stockroom control and inventory maintenance require one (1) minute. These times are then calculated against the number of occurrences to provide the total time (cost).

Formula: No. of occurrences x (1 + 5 + 3) = total time

<u>Or</u>:

Total time = 0.15 x E

Where:

E = no. of occurrences

These repair stages represent all of the operations required to process the modules through the Repair Depot; the distribution will be as shown in Table 3-2. The actual calculations are based on the quantity of modules and function categories of each, proportioned as given in the distribution table and costed using the standard times and formulas shown in Table 3-4, Repair Cycle Operations Worksheet. Table 3-4 shows the applicable steps and operations that each of the module repair categories consists of, as well as the constant time value or formula to calculate the time value based on the given input information. These time values are accumulated by labor category, multiplied by the appropriate labor rate, and the output of the set of calculations is the total time required as well as the total cost.

The values calculated in the above steps are required for several purposes. The cost is calculated and required for budget and funding purposes. The time values are required to calculate the number of people required in each of the labor categories, thus providing an input for personnel staffing and also to be used in calculating the amount of floor space required in the facility, thus providing a means to calculate cost of facility space.

TABLE 3-4

REPAIR CYCLE OPERATIONS WORKSHEET - TIME

MODULE TYPE: TEST METHOD: TROUBLESHOOT METHOD: COMPLEXITY:

OPER. STAGE		OPERATOR DESCRIPTION	VISIBLE DAMAGE			NO VISIBLE DAMAGE					CONSTANT TIME	FORMULA KEY
			1a SCRAP	1b REP/OK	1c REP/REP	2a GOOD	2b NG/SCRAP	2c REP/OK	2d REP/REP	2e REP 3X		
		PERCENT OF FAILED MODULES	A	B	C	D	E	F	G	H		
RS1	1	RECEIVING	YES	YES	YES	YES	YES	YES	YES	YES	0.25	
QC1	2	INSPECTION, INCOMING	YES	YES	YES	YES	YES	YES	YES	YES		.15+ .02C
PC1	3	PROD.CONT.-STAGING	YES	YES	YES	YES	YES	YES	YES	YES	0.35	
	4	a. SCRAP	YES	NO	NO	NO	NO	NO	NO	NO	0.35	
	5	b. REPAIR	NO	YES	YES	NO	NO	NO	NO	NO	0.20	
	6	c. TEST	NO	NO	NO	YES	YES	YES	YES	YES	0.15	
RA1	7	REPAIR,INITIAL	NO	YES	YES	NO	NO	NO	NO	NO	---	REP FORM
TE2	8	TEST EQUIP.SETUP:BY TYPE	NO	YES	YES	YES	YES	YES	YES	YES	SEE TABLE	
PC3	9	PROD.CONT.	NO	YES	YES	NO	NO	NO	NO	NO	0.20	
TT1	10	1ST TEST:PER METHOD	NO	YES	YES	YES	YES	YES	YES	YES	---	TEST FORM
TT1	11	1st TROUBLESHOOT:PER METHOD	NO	NO	YES	NO	YES	YES	YES	YES	---	T/S FORM
PC3	12	PROD.CONT. a. GOOD	NO	YES	NO	YES	NO	NO	NO	NO	0.20	
	13	b. SCRAP	NO	NO	NO	NO	YES	NO	NO	NO	0.35	
	14	c. FAILED	NO	NO	YES	NO	NO	YES	YES	YES	0.20	
RA1	15	REPAIR	NO	NO	YES	NO	NO	YES	YES	YES	---	REP FORM
PC3	16	PROD.CONT.	NO	NO	YES	NO	NO	YES	YES	YES	0.20	
TT1	17	2nd TEST:PER METHOD	NO	NO	YES	NO	NO	YES	YES	YES	---	TEST FORM
TT1	18	2nd TROUBLESHOOT:PER METHOD	NO	NO	NO	NO	NO	NO	YES	YES	---	T/S FORM
PC3	19	PROD.CONT. a. GOOD	NO	NO	YES	NO	NO	YES	NO	NO	0.10	
	20	b. FAILED	NO	NO	NO	NO	NO	NO	YES	YES	0.20	
RA1	21	REPAIR	NO	NO	NO	NO	NO	NO	YES	YES	---	REP FORM
PC3	22	PROD.CONT.	NO	NO	NO	NO	NO	NO	YES	YES	0.20	
TT1	23	3rd TEST:PER METHOD	NO	NO	NO	NO	NO	NO	YES	YES	---	TEST FORM
TT1	24	3rd TROUBLESHOOT:PER METHOD	NO	NO	NO	NO	NO	NO	NO	YES	---	T/S FORM
PC3	25	PROD.CONT. a. GOOD	NO	NO	NO	NO	NO	NO	YES	NO	0.10	
	26	b. FAILED	NO	NO	NO	NO	NO	NO	NO	YES	0.20	
RA1	27	REPAIR	NO	NO	NO	NO	NO	NO	NO	YES	---	REP FORM
PC3	28	PROD.CONT.	NO	NO	NO	NO	NO	NO	NO	YES	0.20	
TT1	29	FINAL TEST:PER METHOD	NO	NO	NO	NO	NO	NO	NO	YES	---	TEST FORM
PC3	30	PROD.CONT.	NO	NO	NO	NO	NO	NO	NO	YES	0.10	
RA2	31	FINAL REPAIR/TOUCHUP	NO	YES	YES	NO	NO	YES	YES	YES	---	.14+.0025S
QC2	32	INSPECTION-FINAL	NO	YES	YES	NO	NO	YES	YES	YES	---	.15+ .01C
PC3	33	PROD.CONT.	NO	YES	YES	NO	NO	YES	YES	YES	0.20	
RS1	34	PACK/SHIP	YES	YES	YES	YES	YES	YES	YES	YES	0.42	
TE2	35	TEST EQUIP.-STORE	NO	YES	YES	YES	YES	YES	YES	YES	SEE TABLE	

3.4 REPAIR DEPOT MANAGEMENT

The operation of the Repair Depot will require management as well as support of the operations in addition to the direct support of the repair functions. This is equally applicable to either Government operated facilities and private industry operations. As long as the facility/operation exists there will be a minimum effort required, even if there is no repair activity, and these efforts will increase as the level of effort in the facility increases.

3.4.1 Depot Management/Support Tasks

There are five separate tasks defined for these efforts, each described below. The work of these tasks is always required, but may not be separated into all of the categories when the operation is small or existing without repair work.

Management

This is a two-part task:

(1) Manager - The manager is responsible for the total operation of the Repair Depot and all of the various activities associated with it. This includes all of the necessary reporting, records, inventory, operations and support. In small operations, these tasks may be performed by a single individual, but as volume increases additional support will be required.

(2) Management Support - This support is provided to the manager as volume increases and includes the filing, maintenance of records, report preparation and accounting. It is a variable effort that depends on the volume of the repair facility and the repair flow.

Inventory Control

This task consists of providing management and control of the inventory of spare and replacement parts, test equipment and its maintenance, repair and production equipment. It includes the responsibility of annual inventory accounting, maintaining of proper stock levels, and the required reporting for all of these areas. In very small operations, it may be performed by the manager but is most generally separated into a separate task.

Test Equipment

Test equipment management is an engineering task that has two parts. One is the responsibility and accountability for the equipment, including its proper storage and handling, records and reporting. The other is the maintenance, repair, calibration and operation of the equipment including support to the testing operations during the repair cycle. These tasks are always separate from the management and consist of both a fixed base element and a variable that depends on repair volume and the size of the facility.

Engineering

Engineering support is a variable task that exists only when there is repair activity. It consists of support for problem solving and analysis during test and troubleshooting where problems are beyond the capabilities of the technicians as well as problems with documentation, equipment operation, design changes and other engineering tasks. When engineering support is required, reporting is also necessary.

3.4.2 DEPOT MANAGEMENT/SUPPORT COSTING

The basic cost principles are a base cost value for the static condition, where the depot exists but is inactive, which is a fixed value. Additional costs, as the activity and operations increase, are based on volume and have two parts: the first being those costs that apply to the management and operation, and the second being those costs that are required for the direct support and management of the repair operations.

Table 3-5 shows the various base (fixed) values for each of the functions, as well as the variable factors for both of the other areas. These values are multiplied by quantity of modules (volume) to derive the final total time requirements, and the total times are multiplied by the applicable labor rates to provide for the costs in dollars. As in the repair operations formulas, the total time values are also a required input to the formulas for computing the number of personnel and the amount of required floor space (facility space) required.

TABLE 3-5

MANAGEMENT COST FACTOR TABLE

	GENERAL DEPOT OPERATIONS		MODULE REPAIR OPERATIONS
	BASE FIXED COSTS	VARIABLE ADDED COSTS	VARIABLE ADDED COSTS
MANAGEMENT FUNCTION	HOURS/MONTH	HOURS/MODULE	HOURS/MODULE
MANAGER: (MMI)			
MANAGEMENT	8.00	0.04	0.20
REPORTS	4.00	0.04	0.05
ACCOUNT'G & RECORDS	4.00	-0-	0.05
INVENTORY	2.00	-0-	-0-
TOTAL	18.00	0.08	0.30
MANAGEMENT SUPPORT: (MSI)			
RECORDS	-0-	-0-	0.10
FILING	-0-	-0-	0.27
ACCOUNTING	-0-	0.04	0.20
REPORTS	-0-	0.04	0.13
TOTAL	-0-	0.08	0.70
INVENTORY CONTROL: (MSI)			
TOTAL	1.00	0.01	0.20
TEST EQUIPMENT ENG'G: (TEI)			
INVENTORY/RECORDS	2.00	0.08	-0-
SUPPORT (AUTO TEST)	-0-	-0-	0.20 x F*
ENGINEERING	-0-	-0-	0.20
TOTAL	2.00	0.08	0.40
ENGINEERING SUPPORT: (EEI)			
SUPPORT (AUTO TEST)	-0-	-0-	0.10 x F*
REPORTING	-0-	0.04	-0-
TOTAL	-0-	0.04	0.10

* AUTOMATIC, F = 1.0; SEMI-AUTO, F = 1.5; MANUAL, F = 2.5.

Most of the costs are not affected by module types and repair/testing methods, but this is not true for the engineering functions. Both test equipment and the engineering support functions are variable in some or all of the functions by the type of testing/troubleshooting methods used, and the applicable factors must be applied. Because of these factors, total values for these tasks cannot be used and costing must address each of the sub-elements of the tasks.

To use the formulas derived from the listed factors, the following definitions are required:

BC - base cost (hours/month)

Q - module quantity (includes all returned modules, both good and bad)

DV - depot variable

RV - repair operations variable

Subscripts: m - manager

ms - management support

ic - inventory control

t - test equipment

e - engineering

__Manager cost/time__:

$$(12 \times BC) + (DV_m \times Q) + (RV_m \times Q) = \text{manhours/year}$$

__Management support cost/time__:

$$(DV_{ms} \times Q) + (RV_{ms} \times Q) - \text{manhours/year}$$

Inventory control:

$(12 \times BC) + (DV_{ic} \times Q) + (RV_{ic} \times Q) = $ manhours/year

Test equipment:

$(12 \times BC) + (DV_t \times Q) + [(.20 \times F \times Q) + (.20 \times Q)] = $ manhours/year

Engineering:

$(DV_e \times Q) + (RV_e \times F \times Q) = $ manhours/year

The output of these formulas provides time which is used to calculate the personnel and space requirements as well as cost. The labor rates are provided in Table 3-1 and are self explanatory. Total cost calculated by these formulas is available for the summary cost of the program.

In calculating the personnel requirements, it is common to have a need for partial people. In most private industry, this means that the required functions are performed by an individual who has other duties as well. In some cases, both private and Government, this may not be true, and personnel must be calculated to the next higher whole number. This is also valid in the calculation of required floor space.

3.5 Replacement Material Costs

The costs of replacement materials consists of two categories: those parts that are replaced during repair and troubleshooting of the modules, and the total replacement of scrapped modules. Each of the categories is explained below.

3.5.1 Replaced Components

Modules returned for repair will require replacement components and parts for those found damaged and/or defective, as well as some that are suspected and replaced. A generic parts list has been derived and costs have been applied to each of the components listed in this list with costs calculated to the Total Cost Level. This list is shown as Table 3-6, and all costs are taken from the Total Cost column. For each module functional category (A through H), a generic parts list is derived based on the size of the module, and its cost is based on the material costs provided in Table 3-6. Since it is impossible to predetermine which part will fail, the cost of each part replaced is taken as the average of the cost of all of the parts for that module size/type. Each time a module enters a repair stage in the cycle, it assumes the replacement of one (1) component, thus the cost can be calculated by the sum of the repair occurrences times the value of the average component for each module type.

TABLE 3-6

MATERIAL PRICES

	PART DESCRIPTION	BASE AVG'D COST	ESCALATED COST(40%)	TOTAL COST (15%)		
1	RANDOM LOGIC 100 GATES	5.28	7.53	8.66		
2	RANDOM LOGIC 100-2000 GATES	42.60	59.64	68.59		
3	RANDOM LOGIC 2000-7500 GATES	470.67	658.94	757.78		
4	RANDOM LOGIC 7500-20K GATES	470.67	658.94	757.78		
5	BIPOLAR ROMS 2.2K BITS	5.83	8.16	9.39		
6	BIPOLAR ROMS 2.2K-17K BITS	31.05	43.47	50.00		
7	MOS ROMS 2.2K-17K BITS	35.40	49.56	57.00		
8	ROMS 17K-38K BITS	110.36	154.5	177.68		
9	ROMS 38K-74K BITS	364.00	509.6	586.04		
10	RAM 1.1K BITS	21.25	29.75	34.21		
11	BIPOLAR RAM 1.1-5000BITS	41.20	57.68	66.33		
12	MOS RAM 1.1-5000 BITS	28.35	39.69	45.64		
13	RAM 5K-17K BITS	17.20	24.08	27.69		
14	RAM 17K-74K BITS	24.68	34.55	39.73		
15	LINEAR IC 1-32 TRANSISTORS	6.10	8.54	9.92		
16	LINEAR IC 33-300 TRANSISTORS	45.73	64.02	73.63		
17	TRANSISTOR NPN	5.88	8.23	9.47		
18	TRANSISTOR PNP	6.58	9.21	10.59		
19	FET	3.80	5.32	7.45		
20	GEN PURPOSE DIODE	2.00	2.80	3.22		
21	ZENER DIODE	2.50	3.50	4.03		
22	LED	1.50	2.10	2.42		
23	MICROWAVE DETECTOR	10.50	14.70	16.91		
24	MICROWAVE MIXER	1.16	1.62	1.87		
25	MICROWAVE ISOLATOR	4.80	6.72	7.73		
26	MICROWAVE POWER TRANSISTOR	101.43	142.00	163.30		
27	RESISTOR, FIXED	.15	.21	.24		
28	RESISTOR, POWER	1.85	2.59	2.98		
29	RESISTOR, TRIMMER	4.00	5.60	6.44		
30	CAPACITOR, MILAR, MICA	1.25	1.75	2.01		
31	CAPACITOR, CERAMIC	1.75	2.45	2.82		
32	CAPACITOR, ELECTROLYTIC	5.25	7.35	8.45		
33	CAPACITOR, VARIABLE	9.50	13.30	15.30		
34	TRANSFORMER, PULSE	12.30	17.22	19.80		
35	TRANSOFRMER, AUDIO	40.00	56.00	64.40		
36	TRANSFORMER, POWER	120.00	168.00	193.20		
37	TRANSFORMER, RF	75.00	105.00	120.75		
38	RF COIL, FIXED	4.05	5.67	6.52		
39	RF COIL, VARIABLE	9.00	12.60	14.49		
40	RELAY	70.00	98.00	112.70		
41	TOGGLE SWITCH	3.50	4.90	5.64		
42	ROTARY SWITCH	12.00	16.80	19.32		
43	CONNECTOR	45.00	63.00	72.45		
44	PWB CONNECTOR	28.00	39.20	45.08		
45	2 SIDED BOARD	75.00	105.00	120.75		
46	MULTILAYER BOARD	350.00	490.00	563.50		
47	CRYSTAL	102.00	142.80	164.22		
48	LAMP, INCANDESCENT	.34	.48	.55		

NOTE: These costs are based on actual costs of representative components for each of the categories shown.

COST ADJUSTMENTS: The 40% escalation factor is the material overhead and allowance factor, and the 15% is the G&A factor.

Table 3-2 shows the anticipated distribution of each module type for each of the anticipated failure categories, and Table 3-4 indicates the various repair stages. Using the data in Table 3-4, each module type can be calculated for the anticipated number of components replaced based on the quantity of returned failed modules. This value is multiplied by the average component cost for that module size/type to derive the total cost of replaced material. The number of components replaced is also a required value for the calculation of the stockroom costs.

3.5.2 Replacement Module Costs

Some of the modules returned for repair will be scrapped as either unrepairable or too expensive to repair. These modules must be replaced in the system pipeline, and a value for the replacement cost must be calculated. Not all systems will require that the Repair Depot replace these modules, in which case the cost need not be calculated.

Each of the eight module types is individual and unique, and its material content varies according to its size. The required labor is also a variable depending on type and size and can only be applied as a factor of the material costs even though this is known to be somewhat inaccurate and further variable. Computation of the cost of each replacement module is based on the total value of the material required for each module size and type multiplied by the given labor factor for the particular type. Since the cost of material is already at the

Total Cost Level, the resulting value is also at Total Cost. Replacement module costs can be computed by the following formulas:

RF Front End	MC x 2.4 = $
RF/IF	MC x 2.8 = $
Analog	MC x 2.2 = $
Power Supply	MC x 2.2 = $
Digital	MC x 1.8 = $
Digital Interface	MC x 1.6 = $
Memory	MC x 1.4 = $
LSI	MC x 1.2 = $

Where:

MC = material costs

NOTE: Labor factor includes both the hands on direct labor and the necessary support labor required for each module type and assumes very low volume type efforts.

3.5.3 Total Materials Costs

The total material costs is the sum of all the replacement component/parts costs and all the replaced modules for all the module types in the system under evaluation. This value is included in the summary cost for the Repair Depot.

3.6 DEPOT FACILITY SPACE REQUIREMENTS

Operation of a Repair Depot requires a facility and a certain amount of space in the facility. The space required is relative to the volume of work anticipated and the number of people that must work there. The volume of work anticipated is an input provided by the number of modules expected to be processed through the Depot, and there are standards for allocating space for particular jobs and types of operations in industry. This section defines the various jobs and provides a methodology for calculating the required space based on the volume of work to be performed and supported.

3.6.1 Space Requirements

Space must be provided for each individual to perform the required tasks as well as to move around the work area and store (temporarily or for a period of time) the incoming and completed work. In addition to the immediate work areas, the equipment(s) required, the stock of parts/stores, and the returned modules must also be provided with storage space and allowances must be made to provide for some unknown requirements.

Table 3-7 shows a listing of space allocations for personnel required on the job based on square feet to be provided in either square or rectangular areas. Each space allocation provides for both the work area and the space required for the person to operate. Storage space is estimated assuming normal flow of work without long holding delays and considering the size of the product(s) anticipated in each case. As with the work

TABLE 3-7

FACILITY SPACE ALLOCATION VALUES

CATEGORY	SPACE REQUIREMENT
Office Worker	40 sq. ft. per person
Receiving	40 sq. ft. per person (includes work area)
Inspection	64 sq. ft. 1st person, 40 sq. ft. each additional
Production Control - Staging	40 sq. ft. per person(office space)
Production Control - Other	40 sq. ft. per person (does not include floor area for in-process materials)
Repair	40 sq. ft. per person
Test/Troubleshoot	25 sq. ft. per person (does not include equipment)
Pack/Ship	25 sq. ft. per person above 1st person (1st person included in work space allowance)
Storage-Receiving	40 sq. ft. up to 1000 modules per month; 25 sq. ft. each additional 500 modules
Storage-In-Process Modules	50 sq. ft. each 500 modules
Stock Room	150 sq. ft. 1st 500 modules per month; add 50 sq. ft. each additional 500 modules
Test Equipment-Floor	100 sq. ft. for equipment, up to 4 operators; add 25 sq. ft. each additional operator above 4
Test Equipment-Store,Maint.	250 sq. ft. for 1 to 4 module types; add 25 sq. ft. each additional module type
Repair Equipment-General	200 sq. ft. up to 2000 modules per month; add 50 sq. ft. each additional 500 modules per month
General Office Space	50 sq. ft. up to 20 people; 100 sq. ft. above 20 people

TABLE 3-7

FACILITY SPACE ALLOCATION VALUES (continued)

CATEGORY	SPACE REQUIREMENT
General Common Space	100 sq. ft. up to 50 people; add 100 sq. ft. each additional 50 people
Reserve Space Factor	15% of total calculated floor space requirements

areas, the storage space includes both actual storage space and the necessary area to move about. Some space requirements are dependent on the module volume and must be projected accordingly. Space allocations must address "whole" people; therefore, when the requirements indicate a "partial" person, a complete space (area) must be allocated.

Test equipment storage includes three elements: the actual storage space for the equipment; the space required for the support and calibration equipment; and work area to perform maintenance, repair and calibration. This will vary somewhat based on the primary types of testing, and the estimated space is taken as an average and may vary from equipment to equipment type.

3.6.2 Space Requirement Calculations

The calculation of space requirements is based on the number of people required and the quantity of modules and module types to be accommodated. Two sets of calculations must be made: one to determine people space and the other to determine equipment/storage space, with a final calculation to provide the total.

Based on the hours' requirements provided by the calculations in previous sections, the total hours for each labor/operation type is determined. The number of people (or partial people) is calculated by dividing these hours by 168 to

determine the people per month. Using the values provided in Table 3-7, simple multiplication will provide the space requirements in square feet.

Calculation of the amount of space required for storage of both modules and equipment, as well as equipment space in some cases, is based on the volume of modules anticipated and the number of types. Calculations must be made separately for each specified area, and Table 3-7 provides requirements as well as a notation of how the space is allocated. The module volume and quantities per type are an input and thus readily available for use in the calculations required.

No calculation or standard values can perfectly project requirements for unknown situations, nor does any facility allow for perfect fits. To compensate for these and other unknowns as well as providing for some reserve space, the total calculated space requirements should be increased by 15%.

The cost of space is a major variable and will fluctuate for many reasons, especially between the private sector and Government owned facilities. In all cases there will be costs for the space required. Costs are based on an annual usage, and the value estimated is $15.00 per square foot, based on the total area required.